A COST COMPARISON OF AERIAL AND GROUND BASED APPROACHES FOR THE CONTROL OF ALIEN INVASIVE PINES IN THE WESTERN CAPE

by

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Declaration

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Abstract

The rugged mountainous areas of the Western Cape fynbos are highly biodiverse, however alien invasive Pines remain a continual threat both in terms of its biodiversity and water supply as they are continually spreading and thriving uncontrollably. Felling has been the main clearing method; however, it has become too expensive and slow to use within these areas in comparison with the speed of the invasion. These environments are complex in that they can vary from site to site in terms of tree density, slope, surrounding obstructive vegetation and remoteness. These site properties often result in longer walk, removal and site access times which can significantly increase overall costs of labour-intensive methods such as felling. The problem is continuing to get worse over time and demands an investigation into alternative clearing methods. Chemical methods such as the Drill and Fill and Aerial Basal Bark Application (ABBA) method have increased the efficiency and scope of alien invasive Pine removal in other countries which have however not been tested for local conditions. The aim of this study was to determine under what site conditions these chemical control methods and the use of helicopters would be more cost effective compared to traditional felling which would encourage an integrated approach to managing the species. The study thus consisted of two novel clearing methods: the Drill and Fill method, the Aerial Basal Bark Application (ABBA) method and traditional felling currently used in practice. A work rate matrix was constructed which compared the financial implications of each clearing method at the various physical site combinations: tree density, slope, surrounding obstructive vegetation and remoteness. Expert knowledge was employed to validate the work rate and costing data. The study found that the higher productivity of the drill and fill teams outweighs their total daily team rate compared to traditional felling. The productivity of traditional felling was prevented by the mandatory higher safety and supervision requirements associated with chainsaw operation which resulted in the inclusion of unproductive team members, in contrast with all members of a drill and fill team using a drill from the added safety of drill operation. The relative lower weight of drill and fill equipment decreases walk times and increases productive working time. Consequently, most scenarios showed the drill and fill method is more cost-effective compared to traditional felling.

The ABBA method is the preferred method at sites where isolated Pines are situated in dense fynbos with difficult access at slope gradients of 45° and higher. At these site combinations, ground teams experience longer walk times which reduces their productivity to such an extent that ABBA is comparatively more cost-effective. Additionally, at slope gradients of 45° and higher, high-altitude teams require specialized equipment which results in further reductions in their productivity. Helicopters should therefore target the species in their isolated spread stages before they reach reproductive maturity and spread large amounts of wind-blown seeds over considerable distances. The study assumed the helicopter had a high level of hours available per annum. In practice however

this may not be the case due to unfavourable weather conditions in these mountainous areas which makes it risky for operators. Government must make use of a private contractor involved in agricultural crop spraying to prevent this from happening, as operations can be diverted to crop spraying in low lying areas when weather restricts invader tree eradication. This would allow the helicopter to work at a lower hourly rate than a government owned helicopter standing idle.

Opsomming

In die ruwe bergagtige gebiede van die Wes-Kaapse fynbos bedreig die uitheemse indringer dennebome beide die biodiversiteit en waterafloop, omdat hulle aanhou versprei en onbeheers floreer. Die vernaamste uitroeimetode tot dusver is om die bome af te kap. Hierdie metode het egter te duur geword en neem te lank in vergelyking met die tempo van indringing. Hierdie omgewings is kompleks omdat hulle van plek tot plek verskil in terme van boomdigtheid, helling, omliggende versperrende plantegroei en afgeleënheid. Hierdie terrein kenmerke veroorsaak langer stap-, verwyderings- en toegangstye, wat die totale koste van arbeidintensiewe metodes soos afsaag aansienlik verhoog. Hierdie groeiende probleem vereis 'n ondersoek na alternatiewe skoonmaakmetodes. Chemiese metodes soos die *drill and fill* (boor en vul) en *aerial basal bark application* (ABBA) het die doeltreffendheid en omvang van die uitroeiing van uitheemse indringer dennebome in ander lande verhoog, maar is nog nie onder plaaslike toestande getoets nie. Die doel van hierdie studie was om te bepaal onder watter terreintoestande hierdie chemiese beheermetodes en die gebruik van helikopters meer koste-effektief sou wees in vergelyking met tradisionele afsaag, wat 'n geïntegreerde benadering tot die bestuur van die spesie sal aanmoedig. Die studie het gefokus op twee nuwe uitroeimetodes: die boor – en vul ("*Drill and Fill")* metode en die *Aerial Basal Bark Application* (ABBA) metode, tesame met tradisionele afsaag soos tans in die praktyk gebruik word. 'n Werktempo-matriks is opgestel om die finansiële implikasies van elke uitroeimetode te bepaal vir terreine wat verskil ten opsigte van boomdigtheid, helling, omliggende versperrende plantegroei en afgeleënheid. Kundiges se kennis is verkry om die werktempo en kosteberekening te verifieer. Die studie het gevind dat 'n boor- en vulspan meer produktief is as 'n tradisionele afsaagspan. Die produktiwiteit van die tradisionele metode van indringerbome met 'n kettingsaag afsaag, is verlaag weens die insluiting van onproduktiewe spanlede a.g.v. die verpligte hoër veiligheids- en toesigvereistes, in kontras met 'n boor- en vulspan se lede, wat almal produktief is weens die groter veiligheid van die boor- en vulproses. Die relatiewe laer gewig van boor- en vultoerusting verkort staptyd en verhoog produktiewe werktyd. Gevolglik het die meeste scenario's gewys dat die boor- en vulmetode meer koste-effektief is as die tradisionele afsaagmetode.

Die ABBA-metode is die verkose metode op plekke waar geïsoleerde dennebome in digte fynbos voorkom wat moeilik toeganklik is as gevolg van steil hellings van 45° en meer. Hierdie liggingseienskappe vereis dat grondspanne vir langer tye moet stap om 'n bepaalde area se indringerbome uit te roei, wat hulle produktiwiteit in so 'n mate verlaag het dat ABBA in vergelyking meer koste-effektief was. Verder vereis spanne wat teen hellings van 45° en meer werk gespesialiseerde toerusting, wat lei tot groter afnames in hulle produktiwiteit. Helikopters moet indringerbome teiken wanneer hulle nog in hulle geïsoleerde stadium is, voor hulle voortplantingsvolwasse word en groot hoeveelhede van hulle sade met wind oor groot afstande versprei. Helikopter ure per jaar word beperk deur ongunstige weerstoestande in die bergagtige

gebiede, wat dit baie gevaarlik maak vir die operateurs. In plaas daarvan dat die staat self ’n helikopter aanskaf wat slegs indringerbome uitroei, behoort die staat eerder gebruik te maak van ’n privaat helikopter kontrakteur wat landbougewasse bespuit in laagliggende gebiede wanneer die weer die bespuiting van indringerbome in die berge verhoed. Die helikopter in privaatbesit sal dus teen ’n laer uurlikse tarief kan werk as ’n helikopter in staatsbesit wat ’n groot deel van ’n jaar nie benut kan word nie.

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Dedication

I would like to dedicate this thesis in loving memory to my father Clive Hilton Boast and brother Bradley Travis Boast who will always have a very special place in my heart.

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List of Acronyms

ABBA:	Aerial basal bark application
AIPs:	Alien invasive plants
AIS:	Alien invasive species
CARA:	Conservation of Agricultural Resources Act
CFR:	Cape Floristic Region
CMS:	Catchment Management System
GIS:	Geographical information system
HATs:	High altitude teams
MD500:	McDonnell Douglas 500
Nbal:	Natural Biological Alien Land Cover Attribute
NEMBA:	National Environment Management Biodiversity Act
OVD:	Obstructive vegetation density
PPE:	Personal protective equipment
SRAT:	Specialized rope access team
SSA:	Sub- Saharan Africa
T&E:	Tools and equipment
TCCMs:	Targeted chemical control methods
UIF:	Unemployment insurance fund
UN:	United Nations
VAL2:	Volume and location tool
WfW:	Working for Water
WIMS:	Working for Water Information Management System
WoF:	Working on Fire

Chapter 1: Introduction

1.1 Background

Alien invasive plants (AIPs) have gained a considerable distribution on a global scale (Early *et al.*, 2016:2). These plants can cause various negative effects in a native ecosystem, such as altering fire regimes (Brooks *et al.*, 2004:680), nutrient cycling (Allison & Vitousek, 2004:618), the hydrology (Le Maitre *et al.*, 2016:665) and even the survival of native species (Mack *et al*., 2000:698). It is believed that alien species are most common in parts of South Africa with the most native plant species, thus making South Africa's most bio-diverse regions continually under threat from alien invasive species (AIS) now and into the future (Richardson *et al.*, 2005). AIPs also include woody species which have been introduced into countries for various uses such as commercial forestry for the supply of round wood and pulp (Van Wilgen & Richardson, 2012:60), but also for the use of fuel wood, soil erosion and desertification (Nawata, 2012:9). Some introductions have however been unintentional; this can be attributed to the increased trading of nations, population growth and the rapid movement of people occurring now more than ever before (Meyerson & Mooney, 2007:199).

The Cape Floristic Region (CFR) is one of earth's known biodiversity hotspots and a global priority (Mittermeier *et al.*, 1998:519; Myers *et al*., 2000:856) . This is because this area holds high value in terms of plant diversity, with 67,8% of these plant species being endemic to the region, showing a high level of endemism (Born *et al*., 2007:152) whereby endemic can be defined as an organism restricted to a specific region or locality (Falk-Petersen *et al*., 2006:1411) . Various processes such as urbanization, agriculture and alien invasive trees have altered around 30% of the CFR (Rouget *et al*., 2003:63). Alien invasive plants however have been recognized to present themselves as the greatest threat to the areas diversity and rare species if left to spread to their full potential (Latimer *et al.*, 2004:81). Alien Invasive trees such as Hakea (Hakea *spp*.), pine (Pinus *spp.*) and wattle (Acacia *spp*.) are the main culprits and have been estimated to cover over 66% of the 750 000 ha at various densities in this region, comprising the most in terms of control costs historically while Pinus was found to be the most prevalent on rugged steep slopes where control is most expensive (Van Wilgen *et al.*, 2016:168). Pines (Pinus *spp.*) are notably problematic in the region; one of the contributors to their spread are neighbouring plantations where the species plays an important role in forestry (McConnachie *et al.*, 2015:117), resulting in their plantings mostly being introduced in areas of the fynbos and on land not largely suitable for other agricultural practices (Van Wilgen & Richardson, 2012:56). Plantations have brought about many negative effects such as spreading beyond these borders outcompeting native plants (Higgins *et al.*, 1999:308), limiting the options for fire management (Seydack, 1992:56), decreasing stream flow and negatively affecting surface water runoff and biodiversity *(*Le Maitre *et al*., 2000:404; Richardson, 1998:23; Van Wilgen *et al.*, 2008:340).

Nineteen *Pinus* species are well established alien plant invaders in the Southern Hemisphere (Richardson & Higgins, 1998:451), however four of the species: *P. pinaster*, *P. radiata, P. patula* and *P. halepensis* are the most widely planted and invasive (Richardson, 1998:22). The species P. *pinaster* and P. *radiata* are however the most important forestry species in the Western Cape and major invaders in the mountain fynbos where their long range dispersal is a continual issue for management, giving rise to scattered satellite foci which eventually lead to dense stand formations (Richardson & Brown, 1986:535; Richardson & Van Wilgen, 1986:315). Their serotinous and pre-adapted capability to fire prone environments, large seed production and resilient nature for withstanding the poor nutrient soil profiles in areas of the fynbos vegetation in the Southern Hemisphere, affords them the ability to thrive and invade large distances outside of their natural habitats (Richardson, 1998:18; Van Wilgen & Richardson 2012:59; Richardson, 1989:79:81) and their distant spread usually gives rise to scattered outlier trees.

Important components in their seedling spread are environmental triggers such as fire, which naturally occurs in the mountain fynbos, and allows them to produce large quantities of seeds over great distances (Van Wilgen, 2009:338). Fires rarely occur in periods of less than eight years in these areas, and most of the species can germinate themselves and establish new seeds in less than seven years (Richardson, 1989:79), thus granting this species a successful survival and spread within the environment. A global review on the literature of naturalized and invasive conifers undertaken by Richardson & Rejmánek (2004:326) concluded that successful Pine invaders have unique life history traits such as small seed masses, short juvenile periods, and intervals between large seed crops. Although their invasiveness is prevalent worldwide, large areas of fynbos mountain catchments in the Western Cape have especially been affected (Cowling *et al*., 2009).

In response to the threat of AIPs, Working for Water (WfW) was initiated in 1995 when it made sense to simultaneously adopt an ecological approach through the potential water supply savings while politically creating employment in the process (Turpie *et al*., 2008:4). Initially, WfW started with ten projects in six of the country's main provinces, having a budget of R25 million and since then has grown to 300 projects across nine provinces with a budget of now R1.5 billion (Van Wilgen & Wannenburgh, 2016:9). Key elements in the programme include the focus on job creation and alleviating poverty through temporary employment by using the bulk of its budget on labour-intensive control methods (Van Rensburg, 2017:14). Arguments have however have been put forth that the programme has not had such great success: inefficiency of control operations (Ground, 2003:15; McConnachie *et al.*, 2012:133). The goal of poverty alleviation of the programme has also constrained the allocation of resources and clearing strategies have only been applied to small portions of the invaded areas, which has resulted in a call for more focused and modified national strategies to be put in place (Van Wilgen *et al.*, 2012:9). Treatments have been applied to standard to less than 15% in some areas at project level, which has called into question the effects these clearing methods have had on reducing AIP densities (Kraaij *et al.*, 2017:7). Some studies have however determined in a large area of the CFR that WfW have effectively reduced alien plant presence, and if it had not intervened would have been 49% higher than currently observed within a large area in the CFR (McConnachie *et al*., 2016:475).

The control of isolated outlier invasive Pines before they reach reproductive maturity and become seed sources has been seen as an essential element of any management plan aiming to slow their dispersal, thus causing priorities of control to shift to preventing their spread in new areas through the removal of lone outlier trees (Ledgard, 2001:55). The species are however becoming denser and more established in remote and inaccessible mountainous areas where it is impractical for mechanical teams to be effective and it has been recognized there exists no viable control options for the removal of invasive pines within these areas (Hoffmann *et al.*, 2011:399; Van Wilgen & Richardson, 2012:64). Mechanical control methods used often involve handheld implements such as axes, to more power-driven tools such as chainsaws which are labour-intensive and can be expensive to use in these remote or rugged areas (Van Wilgen *et al*., 2001a:2). Chainsaw clearing in practice has also been limited to only one worker per team, which results in only one operator actually treating the trees which makes clearing a time-consuming process, thus there have been calls for more mechanised approaches in current clearing teams which can increase efficiency (Shackleton *et al*., 2016:189-190).

Traditional fell and burn strategies on Pine, in some cases from added fuel loads, can result in uncontrolled intense burns negatively altering soil properties and vegetation recovery (Holmes *et al.*, 2000:638; Richardson & Van Wilgen, 1986:314). Intense fires can be lessened if fuel loads are removed from site, however, this solution is limited in inaccessible or rugged areas (Holmes *et al.*, 2000:638). Traditional felling can in some cases also cause site inaccessibility in follow up operations and encourage Pine growth from the soil disturbance and seed fall (Wise & Coetzee, 2001:54; Ledgard, 2001:52). Chemical control methods leaving the tree standing ('kill standing') to overcome these issues are present in operations, especially for large trees in inaccessible areas where material removal is too expensive (Holmes *et al.*, 2005:558). However they have been reported as being a slow and unreliable kill standing approach in practice (Ledgard, 2009:382; Raal, 2005:8).

Such possible solutions recognized include the use of novel control methods to improve the effectiveness of control operations for alien trees, instead of relying on traditional control strategies (Shackleton *et al*, 2016:183). The use of novel control methods has been recognized as vitally important in the future, as such innovations have possibilities in maximising control efficiency while minimizing environmental and economic costs over traditional approaches (Caffrey *et al.*, 2014:13). Such innovations are currently being conducted in other countries such as New Zealand which are also dealing with on-going Pine invasions through the use of various novel chemical control methods

(Nuñez *et al.*, 2017:3106). These novel chemical methods have increased the efficiency and scope of aerial based application of herbicides, using helicopters for spot applications using newly developed spray wands, which deliver a measured amount of herbicide dosage to individual isolated trees (Gous *et al*., 2015a:385).

These novel methods involve controlling emerging outlier Pines before they become problematic, using aerial based spot application of herbicides, which in practice has been reported to be more cost effective and less dangerous in inaccessible areas than previous traditional felling approaches (Gous *et a*l., 2015a:385; Raal, 2019:7). This approach has also allowed control to take place over larger areas and in less time than what was previously possible using the traditional based approaches, while allowing monitoring to take place at the same time of control (Briden *et al*., 2014:371: Raal, 2019:7). Pines gradually break down standing over time, giving the advantage of minimal land disturbance compared to traditional felling methods, which encourages native vegetation regeneration, however if aesthetics is a main concern, then felling has been recognized as the better option (Raal, 2005:13).

AIP clearing strategies operate in an environment with multiple conflicting demands and with limited funds being spent on biodiversity conservation, these funds need to be spent carefully (Margules & Pressey, 2000:251; Wilson *et al.*, 2007:1851). In response to this problem, prioritization has been an important strategy, which however, is not sufficient alone (Forsyth *et al*., 2012:56). Effective frameworks which include actual costs need to be implemented as management objectives that explicitly consider the costs are most applicable for determining an economical optimal strategy (Epanchin-Niell & Hastings, 2010:538) and if not incorporated this may cause implicit assumptions about the costs which may not be justified (Naidoo *et al*., 2006:681). Despite these aforementioned economic considerations involving costs, they have been given much less attention compared to biological values (Frazee *et al*., 2003:286; Moore *et al*., 2004:347-349). Kettenring & Adams (2011:974) further supported this in a systematic review and meta-analysis and found few (29%) papers published from 1960 – 2009 evaluated the costs of invasive species control.

AIP clearing costs are influenced by the work rate or effort needed to clear an area, which is affected by the areas surrounding vegetation density, terrain steepness and ease of access (Burnett *et al*., 2007:130). These significantly increase the overall effort for removal and thus the costs through either long access times to a site or decreasing search and removal speeds over the area in question (Cacho *et al.*, 2006:909). AIPs such as the *Pinus* species reside within complex heterogeneous environments with geographical variations taking place from site to site, which are compounded by logistical factors which prevent simple decisions on how management should optimally allocate their scarce resources for control (Roura-Pascual *et al.*, 2009:1599). Recent reviews (Epanchin-Niell & Hastings, 2010:538) on studies addressing the economic optimal control of invasive species concluded that, while an important component for on the ground management decisions, research explicitly examining the heterogeneity present at clearing sites: both the invasions spatial characteristics and the environmental characteristics in which it resides has been given little attention. Prioritization involving these various environmental complexities which vary from site to site at operational scale have been recognized as an area of need for the *Pinus* species in the CFR as this would lead to better coordination for on the ground management within the area (Roura-Pascual *et al.*, 2009:1601-1603). This can also be called a 'geographically differentiated' strategy which involves management using specific control methods that are most suitable for the species invasion stage and the characteristics of the landscape being invaded which can maximize the efficiency at clearing sites (Grice *et al*., 2011:992-993; Krug *et al*., 2010:4108).

1.2 Problem Statement and Research Question

Alien invasive pines are a continual threat, thriving within the rugged and mountainous areas of the Western Cape fynbos. Current clearing operations involve labour-intensive methods; however, these approaches have shown to be expensive and ineffective to operate within these areas and have not had the desired results in terms of reducing their overall spread in the region sufficiently. The spread of invasive Pines is getting out of hand and demands the investigation of alternative methods to allow faster clearing of Pines.

Novel aerial and ground based chemical methods have increased the efficiency and scope of invasive Pine removal in other countries. Thus far, the rationale for using aerial-based application for controlling alien invasive trees has been based on the expected increase in management efficiency, especially in inaccessible areas. The high direct cost, however, has led to perceptions that aerial-based herbicide application to invasive alien trees is prohibitively expensive and should be reserved for specific conditions where manual labourers' access is inhibited by steep slopes and dense fynbos. Information is required on the relative cost of these novel methods compared to current labour-intensive approaches and more specifically, the cut-off points in terms of tree density, accessibility, and surrounding vegetation, where the application of these novel methods becomes more cost-efficient.

1.3 Aim and Objectives of the Study

Considering the above, the aim of the study was to provide information for recognizing under what site conditions, novel chemical control methods would be more favourable in terms of their costs compared to current alien invasive Pine control methods in the Western Cape. The research findings will help inform the current integrated approach for managing South Africa's invasive alien tree problem.

The specific goals of the research are to:

- Adapt the current ground-based AIP work rate model to conditions of the research area and get a total cost of clearing for traditional methods at the various site combinations.
- Construct work rates and costings for the novel methods.
- Compare the costs of current and novel based methods at the various site combinations.

1.4 Methodology of the Study

To fully understand the origins and progression of alien invasive Pines within the Western Cape, an overview of the literature is provided, firstly viewing the AIP problem in a global context and then placing the problem within the context of South Africa.

To achieve a clear understanding of whether novel weed control methodologies offer cost effective and efficient weed control under certain site conditions, two novel control methods were evaluated: aerial basal bark application (ABBA) and drill and fill methodology with current traditional manual clearing approaches.

Due to time and resource constraints, the study did not try and attempt to create new work rates for current clearing methods, but rather build on the existing national AIP work rate data which has been built over the programme's lifetime, for the planning and implementation of alien plant clearing programmes. These original work rates will be modified based on discussions with operational staff that constructed these work rates and have had the most experience with them in the region. Due to the novel nature of the control methods, no such work rate data exists at present, therefore close consultation was made on their work rates and cost structures with experts in the field who are directly pioneering these methods.

1.5 Outline of the Study

The study begins by focusing on alien invasive plants in terms of their history, management, and their available control methods in a broader global context while, specifically focusing on South Africa and alien invasive Pines. Chapter 3 discusses the methodology and analytical framework used for the ground-based control methods and applies the same logic to aerial based control. Chapter 4 presents the results and findings while Chapter 5 finally provides the conclusions and ends with recommendations and possible suggestions for further research.

Chapter 2: Literature Review

2.1 Introduction

The aim of this chapter is to contextualise the alien invasive Pine problem from both a global and South African perspective and consists of six main sections.

The first section gives broad definition of AIPs, and the AIP problem is then discussed from a South African perspective, in terms of their history and spread and the various negative impacts caused, while further delving into these topics with the *Pinus* species. The section ends by explaining the history of clearing efforts within South Africa and the Western Cape, current national clearing programmes in place and the contractor-based models they follow.

The section following then discusses the management of AIPs within South Africa, and includes the four main strategies for management, phases of control, spatial clearing strategies and elements of best practice. The section ends with current conflicts of interest and private landowner and forestry legislative measures put in place for management of the species.

The next two sections deal firstly with the introduction of the three ground-based control methods: mechanical, chemical, and biological, and the advantages and disadvantages of each are given. A brief history as to why biological control of the species was forestalled has also been discussed to highlight the importance as to why novel control methods are urgently needed for the species future management. The aerial based control techniques: skid hopping, and strop or human sling are briefly introduced.

The section following presents the novel ground and aerial based control methods which will be examined in the research project: the drill and fill and the aerial basal bark application (ABBA) methods. This is important to familiarise the reader with both these novel methods which will be used later in the study for comparison with the chosen traditional approaches.

The final section examines current national AIP management systems, work rate variables and cost components, from a South African perspective, used for contract generation. The section ends with a discussion on current limitations on national AIP work rate data and the purpose of developing these work rates further. Identifying and improving current AIP management systems by considering the various environmental complexities that vary from site to site is tremendously important as it could aid in management decision making and provide potential scope for recognising under what site conditions management can use these novel control methods.

2.2 Invasive Alien Plants

The term 'exotic' can be defined as an organism that has been introduced in an area where they did not exist before, outside their natural range and dispersal potential, or could not occupy without the direct or indirect introduction by humans (IUCN, 2000:5). Some have been introduced in these areas deliberately for a variety of reasons, such as offering economic benefits (Yan *et al.,* 2001:1321), sustaining the human population (Pimentel *et al.*, 2001:1) and for ornamental purposes (Dehnen-Schmutz & Touza, 2008:16). These organisms have also been unknowingly introduced by the global movement of human beings with globalization and increased human interactions accelerating these introductions (Meyerson & Mooney, 2007:199). Species that have colonized an area since the Neolithic period are usually considered 'exotic' or 'non-native' (Pyšek, 1995:72) as before this time man was more intrinsic to nature and his influence on spread was the same as animals (Webb, 1985:232-233), while some authors consider periods before this era more appropriate (Bullock *et al.*, 1997:12). The term 'alien' and 'exotic' have been used interchangeably in the literature (Russell & Blackburn, 2017:312) and simply also means an organism that would not be present within an area had it not been for the movement of people (Pyšek *et al.*, 2004:135). A plant is said to be 'invasive' when its distribution or spread is increasing within the area (Pyšek, 1995:79); the plant has now become naturalized and can produce offspring in large numbers over large distances (Richardson *et al.*, 2000:98). AIPs can cause various negative impacts such as causing displacement of natural habitats and species (Vitousek, 1990; Wilcove *et al*., 1998) economic losses (Paini *et al.*, 2016:7575) and harming human health (Pyšek & Richardson, 2010).

As explained by (Richardson *et al.*, 2000:94) there are various stages present in an invasion:

1) Introduction: The plant or propagules are introduced into an area where it has not existed before, and populations of adult plants are created.
2) Colonization: The originated plants reproduce and create a colony.
3) Naturalization: The colony overcomes physical and biological impediments for survival, new populations are produced, and the plant continues to spread.
4) Invasive: The invading plant reproduces and spreads over large areas.
5) Transformer: The species distinctively alters the character, condition, and nature of the ecosystem over a large area.

2.3 The Alien Invasive Plant Problem in South Africa and the Western Cape

2.3.1 History and Spread

At the start of 2010 South Africa has been exposed to around 8750 introduced plant taxa, 660 of which are recognized as being naturalized, while a further 198 of them have been recognized as invasive in legislation and of these, only 64 are subjected to regular control (Wilson *et al*., 2013:1). AIPs were introduced into South Africa for numerous reasons such as preventing erosion (Roux, 1961:99) developing the forestry industry (Van Wilgen & Richardson, 2012:57), agriculture (Visser *et al.*, 2017:6) and for ornamentals (Foxcroft *et al.*, 2008:33). The introduction of invasive plants was slow in early colonization, however from the 1800s onward the rate at which they spread increased significantly, which coincided with increases in trade and immigration throughout the region (Faulkner *et al*., 2020:324-327). After all the introductions that have taken place in the past, it has now been estimated that about 10 million hectares of South Africa has been invaded by approximately 180 AIP species (Van Wilgen *et al.*, 2001b:147). South Africa also houses the largest amount of alien trees after Australia, consisting of 170 different invasive alien woody plants in the region (Richardson & Rejmánek, 2011:791) .

2.3.2 History and Spread of Alien Invasive Pines

In the 1700s several pine species were introduced into the Cape region by European settlers, in order to secure continual supplies of timber to meet future demand, in response to the growing colony populations. This resulted in the first signs of afforestation taking place in the 1800s (Legat, 1930:36; Burgess & Wingfield, 2001:79). The invasive spread of alien pines was first noted in 1855 (Richardson *et al*., 2008:573) and after being introduced for timber production and presently for on-going commercial forestry has resulted in 57 major species of pines now occupying the area (Van Wilgen & Richardson, 2012: 58).

Of these, nineteen species of Pinus have become established alien plant invaders in the Southern Hemisphere (Richardson & Higgins, 1998:451), while four of these species: *P. pinaster, P. radiata, P. patula* and *P. halepensis* are the most prolific and invasive (Richardson, 1998:22). The reasons for the species continual spread are numerous but, as explained by Hoffman *et al* (2011:399) it is attributed to the inaccessible areas where they grow. This makes present removal techniques ineffective; also, there is an absence of biological control within South Africa, due to conflicting interests between the forestry officials and conservationists. The fynbos biome, which is mostly located in the Western Cape, is the most heavily invaded by the species, especially spreading over large water catchment areas, which supply about two thirds of the region's water supply (Richardson, 1998:23). Pine removal is particularly problematic and compounded by the characteristics of these various species, especially in response to fires, which eventually results in dense stand formations that cause drastic changes to the original flora that becomes difficult to restore (Richardson & Van Wilgen, 1986:314-315). Some of these species also possess high performance on steep slopes and long-distance dispersal of seeds from nearby plantations (Richardson *et al*., 1994:518). Alien pines can alter fire regimes, (Van Wilgen, 2009:339-340), change the behaviour and substance of the ecosystem (Richardson *et al*., 1994:519) and negatively affect biodiversity by eliminating various species and original habitats (Armstrong & Van Hensbergen, 1996:36-37). Invasions like these within the area are said to be increasing and remain a serious threat, despite efforts from implemented control programmes (Van Wilgen *et al*., 2012:35; Fill *et al*., 2017:5-6).

2.3.3 Impacts of Alien Invasive Plants on Water Resources

The United Nations (UN) population prospects (United Nations, 2019:5) predicts the world's population will increase from an estimated 7.7 billion to around 8.5 billion in 2030, 9.7 billion in 2050 and 10.9 billion in 2100. Interestingly much of the increase is expected to occur in Africa due to high fertility rates and slowing pace of fertility decline (Bongaarts & Casterline, 2013:165-167). Sub-Saharan Africa's (SSA) populations can be expected to account for more than half the world's population growth from 2019-2050; total populations of the 47 least developed countries (LDCs) are currently growing 2.5 times faster than the rest of the world and are projected to double in size over this time, with 32 of these LDCs residing in SSA (United Nations, 2019:10). South Africa is a chronically water stressed nation, with water deficits of 17% expected by 2030 and further physical water scarcity predictions predicted in 2025 (Colvin & Muruven, 2017:4-7). Additionally, groundwater represents just 15 % of the total water consumption and yet 65% of the population is dependent on it (Levy & Xu, 2012:206-207). Previously the demand for water was met through various engineering systems; however, this option is no longer feasible due to diminishing rivers and the rising marginal costs of these options. Reasons include development opportunities being distant from sources of demand and deterioration of water quality occurring from human impacts (Smakhtin *et al.*, 2001:330).

Earlier studies on the effects of woody AIP species on stream flow from fynbos catchments was modelled by Le Maitre *et al (*1996:170) which concluded AIPs have severe negative implications on Cape Town's water supply as potential savings in water of 350m^3 per hectare a year from alien clearing would offset their estimated average control costs of R33ha^{-1} $year^{-1}$. The previous study was later adapted by (Versfeld *et al*., 1998:4-10) on a national scale, estimating that water loss accounted for 6.7% runoff and R6.97 billion control costs for the entire country under a scenario of no further spread while at a conservative estimate of a 5% spread per year, the invaded areas could double in a 15-year period. Alien plant control was viewed as being more cost effective than other water supply schemes (Le Maitre *et al*., 2000:397). A later study, which looked more closely at four representative catchments within South Africa, estimated an impact of 6.7% on total surface runoff while the reliability of these estimates was questioned (Le Maitre, 2000:406). In a later study, (Le Maitre *et al*., 2016:668), however these previous questionable estimates were addressed by incorporating more representative flow reduction factors and updated condensed invaded areas which gave more conservative estimations of 2.9% on mean annual runoff being affected whereby the Pinus species was recognised as the second most contributing species to these losses. Nevertheless, other studies have agreed with the findings from these earlier studies, showing clearing of IAPs increases stream flow significantly (Görgens, 2016:17; Preston *et al*., 2018:727; Van Wilgen *et al*., 2008:347), especially in the fynbos and grassland biomes where most annual runoff reductions could take place (Van Wilgen *et al*., 2008:344).

2.3.4 Impacts of AIPs on Water Resources within the Western Cape

The Western Cape fynbos, with some managed as water catchments in mountainous areas are severely threatened by Hakea and Pinus (mostly *P. pinaster),* such that the latter species have invaded large areas, while the Western Cape has been said to have the largest reductions in mean annual runoff compared to other provinces (Versfeld *et al*., 1998:52-53). These mountain catchments are important because they have been said to provide two thirds of the Western Cape's water requirements (Le Maitre *et al.*, 1996:169). A study undertaken by Görgens (2016:17) estimating the impacts of different degrees of AIP invasions on the Western Cape water supply systems concluded possible reductions in future water yield could take place by a further by 130 million m^3 per year if clearing of AIPs ceased. Another study by Prinsloo & Scott (1999:7) described the changes in stream flow from the removal of AIPs in three catchments of the Western Cape also confirmed clearing woody AIPS increased stream flows. Dye *et al* (2001:37) concluded that the removal of riparian wattle has significant reductions on annual evapotranspiration (ET) in the Western Cape. Meijninger & Jarmain (2014:106) later assessed the actual impacts on ET from clearing of IAPs on water resources in the Western Cape using satellite remote sensing data; ET was also confirmed to decrease following clearing of AIPs.

Despite these estimates on the effects of AIPs on water resources, which became fundamental in the creation of the WfW programme (Buch & Dixon, 2009:133), there however still exists various challenges such as the accelerating spread of pines in mountainous inaccessible areas, with no indication of these species decreasing in the fynbos (Van Wilgen *et al*., 2012:32). Insufficient knowledge on clearing treatments has been mentioned (Van Wilgen *et al*., 2012:35-36) and a change in management approach would significantly increase the projects effectiveness, especially for scattered invasions which remain extensive (Fill *et al*., 2017:7-8).

2.3.5 Impacts of Alien Invasive Plants on Biodiversity

The Convention of Biological Diversity (United Nations Environment Programme, 1992:5) describes biological diversity (afterwards referred as biodiversity for simplification purposes) as the '" variability among living organisms from all sources including, *inter alia,* terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part: including diversity within species, between species and of ecosystems". AIPs present one of the greatest threats to South Africa's biodiversity after direct habitat loss (Wynberg, 2002:236). South Africa's National Biodiversity Framework highlights the importance biodiversity will play in reaching sustainable development and AIPS are one of the major pressures on South Africa's biodiversity with woody AIPs posing the greatest risks in terrestrial ecosystems (Department of Environmental Affairs and Tourism, 2008:33-38).

Interestingly, South Africa has one of the most biodiverse regions found on earth which includes three globally recognised biodiversity hotspots such as the CFR (Driver *et al.*, 2005:2). Although these regions additionally have the highest concentration of threatened plants globally, the loss in biodiversity is still continuing (Wynberg, 2002:236). Studies have shown that AIPs have traits of higher growth rates (Grotkopp *et al*., 2001:396), high fecundity and seed dispersal (Trakhtenbrot *et al*., 2005:173) and superior abilities to exploit local resources (Byers, 2000:1236). An AIP obtains these superior abilities once introduced into a suitable habitat that has sustainable resources and a lack of enemy's present (Williamson & Fitter, 1996:169). AIPs can then change the soil nutrient processes (Vitousek & Walker, 1989:247), alter the hydrology (Versfeld *et al*., 1998:70) and promote fire within an area (Van Wilgen *et al*., 2009: 339).

The effects of a loss in biodiversity have been shown to reduce the efficiency of whole communities capturing biological resources (Balvanera *et al*., 2006:1155; Cardinale *et al*., 2006:989). A meta-analysis researched by Cardinale *et al* (2011:587) found that when more biodiversity is present, it makes communities more productive as they contain key species and functional traits. Biodiversity loss has been said to have the same impact of loss on productivity when compared with other drivers of global change such as nitrogen, water, and carbon dioxide (Tilman *et al*., 2012:10394). Research has also argued that previous research has undervalued the amount of biodiversity needed for ecosystems, showing for instance, that the effects of biodiversity loss on ecosystems increases overtime (Cardinale *et al*., 2007:18123; Tilman *et al*., 2001: 843).

2.3.6 Biodiversity and Poverty Alleviation

The UN Millennium Summit that took place in September 2000 saw the introduction of ambitious goals, one of which included the alleviation of poverty (Sachs & McArthur, 2005:394). A final report from the UN on the Millennium Development Goals in 2015 (Ki-Moon, 2015:4), concluded that globally the number of people living in extreme poverty has declined from 1.9 billion in 1990 to 836 million in 2015. Some authors however argue that poverty has worsened (Hickel, 2016:761-762). This is especially the case within SSA; estimates from World Bank (2018:2-3) indicate that by 2030 the number of people living in extreme poverty will rise, whereas in 2015, out of 28 of the world's poorest countries, 27 of these were in SSA, all with poverty rates above 30%, compared to a rate of 13% in other regions. Poverty alleviation is therefore a central issue that needs to be addressed within the region in the near future. South Africa is no exception to this case, currently 29.1% of South Africa's population is unemployed, the highest figure since its measurement in 2008 and one of the country's most pressing issues at present (Statistics South Africa, 2019:1).

One impact often overlooked, is the role of biodiversity on poverty alleviation (Roe *et al*., 2014:13-14). It has been argued that biodiversity can support livelihoods, especially for the rural poor, by providing jobs (Buch & Dixon, 2009:138; Adams & Jeanrenaud, 2008:64), reducing vulnerabilities by providing a critical buffer in response to natural disasters and providing a means to food security and health (Timmer & Juma, 2005:28). This can be achieved through 'Biodiversity Mainstreaming', where the goals of biodiversity conservation and the sustainable use of biological resources are internalized into a country's economic sectors, development models and polices, making a sector's activities dependent on conservation (Petersen & Huntley, 2005:2). Some authors however believe that both poverty alleviation and biodiversity conservation cannot occur together (Robinson, 1993:26; Mcshane *et al*., 2011) and that biodiversity mainstreaming can be hampered by various constraints such as trade-offs taking place at different spatial and temporal scales; for example, markets can operate in the short term and ecosystems over the long term (Cardinale *et al*., 2012:65). One possible way recognised to merge both ecological restoration and alleviate poverty is Expanded Public Works Programmes (EPWPs) (Woodworth, 2006:37), however some authors argue EPWPs have been limited at alleviating poverty within South Africa (McCord, 2004:15).

2.4 History of Clearing Efforts in South Africa and the Western Cape

The negative effects of tree plantings on water resources was only recognized in the mid-1900s and alien pines were eventually addressed in the late 20th century, through various removal programmes. These were mostly centred around concerns about indigenous vegetation, such as the fynbos which covers most of the mountain areas of the Western Cape (Ackerman, 1976:24; Van Wilgen *et al.*, 1997:404). Early clearing efforts which began in 1941, resulted in the first 35 years showing a lack of prevention on spread (Macdonald *et al*., 1989:56) and reasons behind this involved uncoordinated and inconsistent methods of clearing and a lack of ecological knowledge (Van Wilgen, 2009:339). In the mid-1980s integrated mechanical and control methods were implemented, but unfortunately this was discontinued in the late 1980s due to changes in responsibilities for their management and financial cutbacks (Van Wilgen *et al.,* 1997:405). Early estimates of the impacts of AIPs within South Africa mostly concentrated on the environmental effects, such as biodiversity. However, this all changed when later breakthroughs were demonstrated on how current and future water resources could be impacted, which led to the formation of the WfW programme (Van Wilgen *et al*., 2001b:155).

2.5 The Working for Water Programme

In 1995 the WfW programme was initiated in South Africa, with the purpose of clearing alien vegetation by employing people from poor backgrounds and simultaneously saving water resources; large-scale removal operations were thus resumed (Buch & Dixon, 2009:133).

WfW has been promoted as a major role player in the upliftment of rural communities through their direct involvement (Binns *et al*., 2001:347). The programme, implemented through government, is an Expanded Public Works Programme (EPWP), the main goal of which is to address economic empowerment through short to medium term job creation for the unskilled, as well as training and development (Phillips, 2004). There has also been the imperative to integrate conservation needs on private lands worldwide, as private decision makers manage invasions according to their own goals, and will likely not take into account all the social costs (Epanchin-Niell, 2017:3333). Most invaded land is privately owned within South Africa; within the CFR at least 85% of the remaining biodiversity is owned privately (Wynberg, 2002:238). Landowner involvement is thus important and if not addressed reinvasion would be of high occurrence (Van Wilgen *et al.*, 2012:36).

2.5.1 The Contractor Based Model

WfW follows a contractor development approach, task-based system, whereby beneficiaries are compensated on completion of a clearing site. According to legislation, AIP clearing is undertaken by contractor teams consisting of 11 working team members and the contractor who competitively tenders to clear the site (Buch & Dixon, 2009: 133; Hough, 2010:38; Hough & Prozesky, 2013:2). The WfW contractor-based model sets maximum prices that can be accepted for clearing a specific area, which is largely based on wages set by the programme and the number of person days allocated to complete the work (Cheney, 2019:139). Contractors are thus responsible for completing contracts specified by WfW and recruiting and managing their teams, while workers are employed by the contractors who enter into employment contracts with them (Coetzer & Louw, 2012:793). Contractors develop the required quotations for clearing, which must comply with the programme's clearing work rate norms and standards, health and safety standards and other employment conditions for workers, while their performance at clearing sites is captured in terms of person days per hectare, cost per hectare , team size and invasion density (Morokong *et al*., 2017:277-278).

Contractors in the programme must abide by health and safety requirements set out in the Occupational Health and Safety Act 1993 (Act No. 85 of 1993) which states that precautionary measures must be put in place for protecting the health and safety of workers (Martens *et al*., 2021:47-49). The programme achieves this by providing and outlining the necessary Personal Protective Equipment (PPE) and tools for the various clearing roles to be used per clearing role in the programme's operational standards (Working for Water, 2007:57-59).

2.6 Alien Invasive Pine Management in South Africa

2.6.1 Prevention, Eradication, Containment and Control

Prevention can be defined as the exclusion or keeping out of an alien invasive species (AIS) from a certain area. This is the most cost effective and effective option in terms of protecting biodiversity from the harmful effects of AIS (Tu, 2009:14). While **Eradication** can be defined as the complete long-term elimination of an AIS within a given area (Tu, 2009:20). This usually involves the early detection and removal of small, isolated individuals before AIP populations undergo rapid spread rates, which is recognized as a the most cost-effective strategies compared to other long term control strategies, as costs of removal can be decreased from preventing large-scale populations forming later (Hobbs & Humphries, 1995:768; Wittenberg & Cock, 2001:131). Eradication is a cost-effective option on arrival and adaptation stages, however early detection is needed and the species must be detectable at small and isolated densities, this is where success is most achievable (Van Wilgen *et al.*, 2001a:3; Simberloff, 2003). This is however challenging as this method requires using successful monitoring systems which ensure that the species in question have been eradicated and the resources used in the eradication programme have not been wasted (McNeely, 2001:28).

Eradication of plant species has been seen to be particularly difficult compared to other AIS, since AIPs can have dormant seed banks and high rates of reproduction and dispersal (Panetta, 2004:525). Prevention and early detection and eradication are the most cost-effective measures; however various barriers to achieve this exist, such as a lack of project awareness, knowledge and even technology (Tu & Robison, 2013:529). Eradication is most cost effective when a rapid response is achieved in response to early detection; however, careful analysis of the costs involved must be present at the outset to achieve success (Wittenberg & Cock, 2001:131). When eradication is not a feasible or is impractical, then control involving long-term continual maintenance is the next best option (Wittenberg & Cock, 2001:133).

2.6.1.1 Control

Control can be defined as suppression of the AIS abundance, typically below an acceptable threshold value which most importantly involves a long-term continual maintenance commitment (Tu, 2009:20). A control method is dependent on various factors of the infestation, for example its size, density, accessibility and its surrounding vegetation, the combination of these variables affects the cost efficiency and the possibility of using a given method in practice (Froude, 2011:27; Ledgard, 2009:381). Although in practice, the combined use of the different methods is normally utilised for cost effective control and can be defined as integrated control (Van Wilgen *et al.*, 2001a:2).

2.6.1.2 Phases of Control

The control of alien invasive plants is not a once off activity and any control programme must include the following three phases: initial control, follow up control and maintenance (Martens *et al*., 2021:11).

Initial Control for the Pinus species in their adult life stages involves the ‘fell and burn’ method due to their serotinous non-sprouting nature which is the universal method used by WfW for the species (Holmes, 2000:7). The ‘fell and burn’ method involves felling the species with a chainsaw and a prescribed burn is undertaken 12- 18 months later under cool weather conditions to kill the resultant seed and seedlings (Holmes, 2000:7).

Follow Up Control can be defined as areas that are re-cleared again after the initial clearing has taken place, with the objective of removing possible regrowth, either from re-sprouting alien species or the germination from soil stored seed banks (Marais *et al*., 2004:97). Follow up control is thus important because if not done, progress gained from initial clearing can be lost through the re-establishment of AIPs after initial clearing (Marais & Wannenburg, 3008: 529). Follow up control for the *Pinus* species usually takes place within 2- 4 years after a fire or prescribed burn, which involves removing any surviving seedlings before reaching reproductive maturity through either hand pulling or cutting using pruning scissors (Marais, 1998:35). Pines are a non-sprouting species and tend to have a lower number of follow-ups compared to other major woody AIPs such as acacia and eucalyptus (Marais & Wannenburgh, 2008:534).

Maintenance control can be defined as a level of control where eradication is seen as an unrealistic option and so the infestation is reduced to a level where it can be contained at a low control cost forever with low commitment to prevent re-infestation (Goodall & Naudé, 1998:116; Van Wilgen *et al.*, 2016:171).

2.6.2 Spatial Clearing Strategies

Spatial clearing efforts can be focused at removing scattered populations far from the larger source population. For instance, Moody & Mack (1988:1009) used a non-spatial simulation of plants spreading by various foci to see whether clearing either the original dense invasion or the scattered 'outliers' were more effective in terms of future population size. It was found clearing less dense isolated stands was more effective, because areas of satellite foci eventually exceed the original populations. Thus, highlighting control should be focused on satellite populations; control costs were however not incorporated. Spatial simulation models for *P. pinaster* in fynbos communities in the Cape Peninsula South Africa (Higgins *et al*., 2000:1833) which assumed clearing costs increase with density, also found strategies involving the clearing of low-density outlying juvenile stands were most cost effective and that delaying clearing had the most significant negative effects on an areas costs of clearing and ecology. As noted by (Mack & Lonsdale, 2002:167-168) in successful control programmes, whether in terms of eradication or control, most success was achieved when satellite populations were removed, helping to prevent the future formation of denser stands and remaining a key component in containment strategies.

Other studies (Wadsworth *et al.*, 2000:37) however opt for contrasting approaches; they suggest it is more effective to focus on the larger core populations, as larger populations contribute more to seedling generation and spread. Other recent work (Taylor & Hastings, 2004:1049) which considers different budget scenarios, has pointed out that under uniform costs and when population densities are low with higher spread rates, removing low density satellite populations would be the most cost effective under low and medium budget scenarios, while removing high density stands under higher budgets would be more effective. Some models (Sharov & Liebhold, 1998:1170) have considered the space occupied or the spatial characteristics of the invasion in reducing the spatial spread of an infestation by deploying resources at its growing edge through 'barrier zone' management.

2.7 Elements of Best Practice

Various aspects of alien invasive plant control can be optimized. Best management practices of an AIP often involve a management system made for a particular species and location (Wittenberg & Cock, 2001:143).

2.7.1 Adaptive Management

The management of AIPs exists in an environment with complex interactions and managers are often faced with uncertainty in their decisions, which can prevent optimal strategies being recognised (Roura- Pascual *et al*., 2009:5). Adaptive management can be described as continuous cycles of actions involving monitoring, learning, and adjusting, that increases the efficiency of control as managers can see the effects their interventions have had and how they interact with these uncertain factors. This has been recognised as an element of best practice for managing AIPs and such examples applied to pines involve using fire after 1- 2 years of felling where seeds are released, which is used to kill any developed seedlings, (Nyberg, 1999:2; Van Wilgen *et al.,* 2001a:6).

2.7.2 Integrated Control

Integrated control involves combining two or more control options, often mechanical, chemical or biological combinations (Esler *et al.*, 2010:211) which is achieved by harmonizing them in an organized manner, by making them compatible with each other and combining them into a multifaceted and flexible system (Goodall & Naudé, 1998:115-116). Decisions on managing and combining these control options are determined by multiple factors, such as the biological aspects of the specific plant, the present factors that cause uncertainty (climate variation, fire etc.), and lastly the human activities taking place: this is determined by the clearing budget and the skill and knowledge of labour (Van Wilgen *et al.*, 2001a:6). Integrated control is mostly prevalent in the exponential growth spread stage where there are multiple populations. For pines, mechanical and chemical control options are used with fire, however these options become limited once populations reach the last stages of spread and dominate the total area (Van Wilgen *et al*., 2001a:2-3). One way to successfully maximize the benefits and minimize the impacts in sustainable ways for alien trees would therefore be to integrate and develop these strategic approaches using a 'toolbox' method of control (Van Wilgen & Richardson, 2014:724-725). This toolbox method involves not some, but all appropriate control options based on the species potential value and invasion stage; for instance widespread alien trees with significant benefits require sustainable reduction of impacts by integrating mechanical, chemical and biological control methods, along with prioritizing different spatial scales that take into account where the highest benefits can be achieved (Van Wilgen *et al.*, 2011:1069). Integration has been seen as a way to achieve best management practice in AIP management (Wittenberg & Cock, 2001:157).

2.8 Conflict of Interest in the Management of Alien Invasive Pines

Alien invasive tree species can in some cases concurrently provide benefits and cause negative impacts, which can lead to difficulties in finding efficient and fair solutions between interest groups (Wise *et al*., 2012:80). These conflicts from alien invasive trees often take place when stakeholders have different viewpoints or value systems, often enhanced by incomplete understandings, which can sometimes change over time through new knowledge or changing value systems (Van Wilgen, 2012:1). Complexities present are normally case specific, containing combinations of values, perceptions and institutional issues that compete among different stakeholders (Estévez *et al.*, 2015:27). Invasive Pine species are categorized as ‘conflict generating species’ in that their high negative and positive impacts can cause significant disagreements and contrasting views between different stakeholders on their potential benefits and impacts (Zengeya *et al*., 2017:7). The *Pinus* species were first viewed as assets but as time progressed, they were also seen as threats, however sometimes only one of these views is held between different parties, causing conflicts to take place (Van Wilgen, 2012:1). These conflicts increase when factors such as their area, the number of the species planted and their time since introduction increases (Van Wilgen & Richardson, 2014:724).

The *Pinus* species were initially viewed as complex but manageable, however as time progressed they continued to spread into inaccessible areas, where wildfires have supported their more geographical extent, making control more difficult and thus adding more complex factors and contrasting views on their advantages and disadvantages (Woodford *et al.*, 2016:72). Dickie *et al (*2014:712) mentions three areas where these contrasting views over alien tree removal occur, such as when the tree species provides direct economic benefits that is primarily centred on the provision of services. These benefits and costs from conflicting species can vary according to the stage of the invasion whereby costs can rise rapidly from their rapid invasive potential and eventually exceed the benefits realized, which further increase, through delays, for their removal (Shackleton *et al.*, 2007:123). The previous statement is in accordance with studies (De Wit *et al*., 2001:176) showing the benefits of many forestry plantations are often smaller than the costs experienced, making ‘do nothing’ approaches of control outside plantations unsustainable and better options to realize greater benefits would be in combining various control techniques.

One of these contrasting views that causes much conflict amongst stakeholders of the *Pinus* species within South Africa, is the commercial forestry sector where the AIPs play significant roles in providing economic benefits for communities, such that planting has taken place outside of their natural areas for centuries (Richardson *et al*., 2008:573). Two Pinus species: *P. pinaster* and *P. radiata* have become major invaders and the most important forestry species in the mountain fynbos compared to other native trees due to their life history traits which afford them high survival rates, rapid growth, survival on nutrient poor soils and providing a more readily available seed source in these areas (Richardson *et al*., 1990:632). The species have however become highly invasive, whereby key environmental and species attributes for their high invasiveness include: smaller seed masses, short juvenile periods; large seed production; high serenity; high fire resistance and short intervals between large seed crops (Higgins & Richardson, 1998:80). Larger invasive Pine stands, as recognised by Richardson *et al* (1994:518), have been located in close proximity to plantations for commercial or amenity purposes, suggesting their higher densities of arriving seeds and seed source proximities increase the chances of an invasion.

These large amounts of seeds from plantations invade adjacent fynbos areas as well as areas set aside for conservation and water production, further place difficulties on how to assign the responsibility in managing them (Cowling *et al.*, 2009:147; Van Wilgen, 2013:39)

2.9 Legislation

Several methods have been put in place for dealing with issues of delegating responsibilities for their management, such as The Conservation of Agricultural Resources Act (CARA) of 1983. CARA was revised in 2001 by classifying weeds into three categories; category two accommodates AIPs possessing commercial value, which presently include six Pine species (Van Wilgen, 2012:2). Landowners must hold permits if the species are to be grown within certain boundaries and their products can be traded, provided steps are implemented to limit their spread (Van Wilgen *et al.*, 2011:1068).

Other legislation that has recently been introduced includes 'The National Environment Management Biodiversity Act' (NEMBA, Act No. 10 of 2004) with regulations aimed at addressing some weaknesses in CARA such as regional variation, the monitoring and compliance of regulations and stricter penalties for non-compliance (Cronin *et al.*, 2017:926-927). This legislation was seen as an instrument which would encourage private landowners to control alien AIPs (Urgenson *et al.*, 2013:2). Certification bodies for forestry plantations and their processes (Forestry Stewardship Council, 2015:18-19) have encouraged biological conservation using various principles, such as carefully controlling and continually monitoring their forestry practices while using non-native species.

It has however been argued that the use of these legislative measures is not having the desired results in practice, such that plantation managers are unable to reduce the spread of Pines, while the legislation and certifications are loosely put in place or ignored entirely on a continual basis (Van Wilgen & Richardson, 2012:64). Additionally, large remote fynbos areas within the Western Cape have many unprofitable plantations, neglected by AIP management and handed over to conservation agencies without adequate funding for their effective management (Cowling *et al.*, 2009:147).

2.10 Ground Based Control Methods

Methods used for clearing alien invasive plants in the Fynbos by WfW can be described as highly labour intensive and aimed at providing jobs for the unemployed (Marais, 1998:35).

2.10.1 Mechanical Control

Mechanical control can be defined as damaging or removing the plant using physical action (Hoare, 2016:24). Defining factors in decision making of all mechanical means can be attributed to the ease of access of the target tree, mechanical Pine control often requires high amounts of diligence for success as all green foliage has to be removed when cut and complete removal needs to take place when hand pulled to prevent re growth (Nuñez *et al.*, 2017:3106).

Examples of Mechanical Control for the *Pinus* species include:

- Hand Pulling
- Lopping/ Pruning
- Felling
- Ring barking
- Frilling

The advantages of mechanical control are that it can be highly effective in areas with low infestation, while having high potentials for creating jobs and alleviating poverty (Hoare, 2016:24). Disadvantages of mechanical control include that it can be expensive and time consuming, especially over widespread infestations that are dense and difficult to access for ground teams (Culliney, 2005:134; Hoare, 2016:24).

2.10.2 Chemical Control

Chemical control can be defined as the application of registered herbicides directly to the infestation of the invasive plant (Van Wilgen & Moran, 2007:4) by changing the chemical environment of the plant, disrupting its physiology long enough to kill it or significantly limit its growth (Zimdahl, 2018:357). Herbicides can be non-selective, which can be described as affecting all vegetation as they affect the same physiological processes common in all plant species while selective herbicides will only damage plants carrying the specific biological pathways they target (Venner, 2006:52).

The advantage of chemical control is that in some cases it is safer in terms of worker safety and more cost effective than mechanical methods (Dampier *et al.*, 2006:524; Fortier & Messier, 2006:810). The advent of new novel chemical application methods have shown that larger more scattered populations can also be treated more cost effectively and in less time compared to traditional mechanical methods such as felling (Gous *et al.*, 2015a:385).

The disadvantages of chemical control is that there can be the risk of environmental pollution and hazards to non-target species or human health, which causes concern over its use, therefore the method is significantly controlled by legislation and requires high levels of training which can prevent its use on large scales (Culliney, 2005:135; Van Wilgen *et al.*, 2001a:2).

Examples of Chemical Control for the *Pinus* species include:

- Foliar Application
- Ground Based Basal Bark Application (GBBA)
- Tree injection

2.10.3 Biological Control

Biological Control can be defined as the introduction of a natural enemy of an exotic origin to control a pest, which is usually also exotic for the purpose of permanent control of the pest (Van Driesche & Hoddle, 2009:115; Hajek & Eilenberg, 2018:22). Through the introduction of the plant's natural enemies into an area where they have become a problem, their invasiveness can be supressed (Brockerhoff & Hoffmann, 2004:67). This suppression for the *Pinus* species, can be achieved by introducing seed and cone feeding agents that effectively cause reductions in their seed supplies which reduce their overall invasiveness (Moran *et al.*, 2000:946).

Advantages of this control method are that when combined with other forms of control such as mechanical and chemical, it can help provide a decrease in the density of AIS over the long term (Van Wilgen *et al*., 2013:537). Biological control using specific insect herbivores and plant pathogens can also be a self-sustaining, cost effective and a self-dispersing tool, especially when compared to mechanical and chemical control options which can be difficult and expensive over large areas with difficult terrain (Fowler *et al*., 2000:554).

The disadvantages of biological control, when compared to mechanical and chemical control methods are its effects and effectiveness are not immediate but slow acting, and in some instances outcomes can be uncertain with risks that once implemented its effects become unrestricted and irreversible (Culliney, 2005:139)

Early on in WfW clearing projects it was realised the clearing of *Pinus* via mechanical and chemical means had major weaknesses such as regrowth after clearing taking place, due to the species soil stored seed banks which encouraged research on biological control. Attention was focused on seed and cone feeding insects as possible solutions for three target species*: P. pinaster*, *P. radiata* and

P. halepensis (Moran *et al.*, 2000:945-946). This was because these agents could lessen the conflicts taking place between the forestry industry and conservationists, while the seed reductions could decrease their overall invasiveness in the long term (Van Wilgen & Richardson, 2012:60). The research led to the discovery of one agent: *Pissoides validirostris*. Although the agent was recognized as meeting all the requirements for being potentially effective and safe, it was however discontinued due to concerns of pitch canker, a major Pine pathogen that could possibly have negative effects on the forestry industry (Lennox *et al.*, 2009:183). Biological control for the species has therefore not been implemented, and this could have provided a solution as the species can produce vast amounts of seeds, especially after fires over long distances. They are becoming denser in large inaccessible mountainous areas of the fynbos, making it practically impossible for traditional mechanical clearing teams to clear these areas (Hoffmann *et al*., 2011:399).

2.11 Aerial Based Control Techniques

The aerial application of herbicides using helicopters compared to other fixed wing aircraft have various advantages, such as having the ability to land and refuel herbicides at treatment sites, while its speed flexibility and manoeuvrability with the added rotor wake effects allows even and precise herbicide application especially in rough terrain (Edwards, 1979:54-55). Forestry operations in New Zealand prefer helicopters over fixed wing aircraft because areas can be remote making time to and from airstrips for landing and refuelling a long and expensive exercise (Gous, 1996:45) while in recent decades the use of helicopters have been applied successfully for weed control in non-agricultural settings (Thistle *et al*., 2014:24). Compared to traditional ground-based approaches it can prevent operator fatigue from carrying heavy equipment or accessing a site, thus allowing more energy to search for outlier populations and having the added advantage of monitoring weed populations while in transit (Knapp *et al*., 2011:190). While being relatively easy to mobilise for AIP control, helicopters can however be expensive, more technically demanding and requiring well-trained operators in rugged terrain (Raal, 2012:14).

2.11.1 Aerial Control Techniques

This technique can be used to transport ground operators to locations of difficult accessibility on foot such as mountainous areas or in delicate environments where driving is not practically feasible and once on site, ground workers use combinations of ground-based techniques previously discussed (Woods, 2007:30)

Skid Hopping can be described as a technique often used for the treatment of scattered *Pinus* populations whereby the operator is transported to each individual tree with a helicopter which is then felled using a chainsaw (Clifford *et al*., 2013:11; Gous *et al.*, 2015a:381).

Strop or Human Sling is a method which is usually used where the species is occupied on steep locations, such that the operator is also transported to each individual tree with a helicopter; however the operator is attached to a strop under the helicopter which increases the risk to the operator and as such the method requires strict safety standards and highly trained workers (Woods, 2007:31).

2.12 Novel Removal Methods

Recent new developments in herbicide control tools for alien invasive Pines have allowed larger areas to be treated in less time and at the same cost of traditional approaches, while significantly increasing the efficiency of control thus making the goal towards their effective management more realistic (Ministry for Primary Industries, 2014:23). The drill and fill and the ABBA novel methods both have some commonalities present, in that they are both targeted chemical and 'kill standing' control methods:

Targeted chemical control methods (TCCMs) can be described as applying herbicides directly or specifically on individual plants for control (Dufour-Dror, 2013:5). Chemical control can be an expensive exercise if used over large areas, and can often cause negative non-targeted environmental effects, thus making 'spot' or 'targeted' chemical methods more beneficial where broadcast applications would be wasteful and more environmentally damaging (Richardson *et al*., 1996:265).

TCCMs have certain advantages over other chemical control methods in that their target specificity causes less harm on surrounding environments and are less expensive due to the smaller herbicide volumes. There is also increased control accessibility using lighter equipment (Dufour-Dror, 2013:5; Gous, 1996:44). Applications are therefore on a stem-by-stem basis, which gives operators the added advantage of adjusting the herbicide rates on an individual basis when necessary and allowing larger trees, which often require higher doses to be treated (Miller & Mitchell, 1990:21).

Both methods also use a 'Kill standing approach' which is often preferred over felling, if indigenous vegetation regeneration is a priority or when an area can have the possibility of future accessibility issues from felled material, which can hamper follow up operations (Wise & Coetzee, 2001:54). Indigenous vegetation can be affected by felling, because in some cases felled trees can cause significant disturbance and mineral exposure to the soil, while in the process also causing seed fall from the felled Pine (Ledgard, 2001:52). Pines also require high light conditions in order to germinate, and felling can support this through the creation of 'light wells' on the canopy floor (Macalister, 2010:18) (see Annexure A).

2.12.1 Ground Based Control

2.12.1.1 Drill and Fill

Tree injection provides more direct control by placing the required chemicals directly into the host tree, which prevents some of the negative environmental and social impacts that take place from conventional foliar chemical applications (Sánchez-Zamora & Fernández-Escobar, 2004:73). Herbicides are applied directly into the tree's vascular system, thus giving various advantages compared to conventional foliar spray applications, in that the chemicals are rapidly absorbed into host plant (Gous & Richardson, 2008:174). Less herbicide and drift reduce their environmental impacts, especially when used near water sources such as in riparian areas (DiTomaso & Kyser, 2007:60).

Tree injection includes cut surface techniques where herbicides are applied to the tree's cambium layer and outer sapwood, by making wounds or cuts in the trees' bark that holds the herbicide in place (Miller, 1988:89; Miller, 1993:270). Techniques include frilling which involves hacking the tree with an axe or hatchet at even intervals around its trunk through the bark and applying herbicide to each cut (Dufour-Dror, 2013:21-22). Hatchet or axe cut methods, although having more direct control, cuts are still exposed and may lead to possible leakages resulting in efficacy losses and possible negative non-target environmental effects (Itou *et al.*, 2015:249). To overcome this problem, techniques such as ring barking can be used, which can be described as the complete removal of a strip of bark around the entire trunk of the tree for disrupting its translocation (Moore, 2013:87). Frilling and ring barking, which results in trees being left standing after their control, are the preferred methods in operations for larger trees in inaccessible areas where felled material removal becomes too impractical and expensive (Holmes *et al.*, 2005:558)

Ring barking can however be an expensive and time consuming process, especially on larger Pines which can increase clearing budgets significantly (Macalister, 2010:19; Macdonald & Wissel, 1989:44) while also being observed in operations as unreliable due to the high chances of incomplete tissue removal and insufficient herbicide application making the tree recoverable (Ledgard, 2009:382; Wise & Coetzee, 2001:62). Therefore, due to these drawbacks, it has been encouraged to use other alternative kill standing approaches whenever possible over ring barking for controlling alien invasive Pine (Raal, 2006:11).

While compared to drilling methods, hacking techniques such as frilling can also limit the amount of chemical placed per cut and can be more time consuming which makes its overall effectiveness arguable (Raal, 2005:14). A study by Donald (1982:3-5) on the control of *P. Pinaster* in the fynbos biome showed that applying herbicides in drilled holes was more economically viable for widely spaced invasions compared to felling, while having better herbicide retentions and distribution compared to the broken nature of the axe cut (frilling) method which resulted in less herbicide use without compromising kill efficiency.

This control method has recently been successfully achieved at a large scale through various groups in New Zealand such as the Marlborough Sounds Restoration (2019:1-2) and the Department of Conservation (Raal, 2005:9-11) for controlling invasive *Pinus* species through the drill and fill methodology, whereby herbicide is directly applied to the tree through holes drilled around its trunk.

Figure 2.1: Operator Using the Drill and Fill Methodology on an Alien Invasive Pine
Credit A. Macalister

The Marlborough Sounds Restoration Trust (2019:1-2) has noted that this method is presently widely accepted and efficient in controlling invasive Pines in New Zealand and preferred over felling as it avoids any land disturbance or damage to the surrounding native vegetation, while also encouraging vegetation regeneration as trees die within two years and gradually break down over 12-15 years. The method is also more accepted than other chemical methods such as spraying, because all the herbicide becomes enclosed within the tree, with no discharge into the air, land and waterways, and no effects on non-target trees in proximity. This in comparison to felling, as explained by Macalister (2010:18) the trees are left standing and therefore have less impact on native vegetation, which provides a smoother transition to native vegetation. This in contrast to felling which breaks down large amounts of native vegetation creating 'light wells' on the canopy floor which can encourage pine seedling generation (see Annexure A). Some researchers have however argued the kill standing approach could encourage pine seedling spread, compared to felling in the study area and as such, it would be encouraged to use the kill standing approach before the species reach reproductive maturity (Van Wilgen, personal communication, 2020).

The method requires the operator to drill holes for herbicide injection not too far in, but only into the trees sap wood at a 45-degree angle at even 40cm spacing's around the tree, while 10ml of herbicide is then immediately applied after the drilling of each hole (Raal, 2019:11-12). Drill and fill best practice guidelines mention an operator can use a drill of either a petrol powered or electric nature (refer to Annexure B). The latter however, due to its electric power supply as mentioned by Badalamenti & La Mantia (2013:3), could place limitations on the number of stems to be treated. Solutions implemented in extending the number of stems to be treated, have involved operators carrying spare batteries while in the field (Macalister, personal communication, 2019). The battery version however, compared to other ground clearing methods could be lighter to carry for operators compared to heavier equipment such as chainsaws especially in dense surrounding vegetation or steep terrain. The methodology is further explained graphically in Figure 2.2 below.

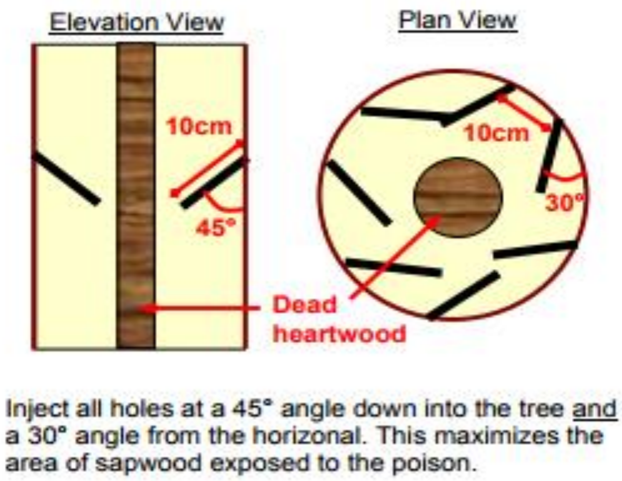

Figure 2.2: The drill and fill methodology
Source: Raal (2019: 11)

2.12.1.2 Additional Equipment

The herbicide can be dispensed using a ‘squirty’ bottle fitted with a nozzle while alternatively using a herbicide pack attached to a calibrated drench gun (Biosecurity New Zealand, 2020a:4). As recognised by Boyd (1985:26-27), the latter option can give operators the added advantages of faster treatment times, more mobility, and the added ability to deliver measured amounts of herbicide into each drilled hole.

2.12.2 Aerial Based Control

2.12.2.1 Aerial Basal Bark Application (ABBA)

The concept of targeted aerial control has been trialled in the past, whereby innovations included the ‘spray ball’ or ‘pyramid’ technique by Throop *et al* (2013:3) who found that the technique would allow plants to be individually treated, while minimizing non-target effects and giving ground crews the ability to access areas currently inaccessible which can be time consuming and dangerous. The concept has also been evaluated for use in riparian areas for insect control by Richardson (2002:168) as a solution to minimize drift, however due to the small droplets and high release heights in this case it was concluded to be ineffective. The targeted aerial control method was compared to a traditional broadcast application by Strand *et al* (2014:1) as a solution for minimizing non-target effects in sensitive areas compared to the broadcast method and it was concluded the spot gun method has high potential in providing maximum host coverage while minimizing impacts on the non-target environment.

The control of isolated outlier invasive Pines before they reach reproductive maturity and become seed sources has been an essential element of any management plan aiming to slow their dispersal (Ledgard, 2001:55). Such control methods for controlling these isolated or clusters of Pines, which are usually costly to treat, have been successfully adopted by the New Zealand Department of Conservation using a helicopter mounted spot application gun (Figure 2.3) to deliver a measured amount of herbicide dosage to each tree crown (Gous *et al.*, 2015a:385)

Figure 2.3: Alien invasive Pine being treated using the ABBA method
Credit M. Mawhinney

The ABBA method involves placing a stream of liquid into the centre of the trees top crown which runs down its trunk, while the helicopters downwash forces the liquid down into the canopy, allowing minimal non-target impacts to take place on surrounding vegetation (Gous *et al.*, 2015a:382-383). The herbicide is absorbed by the tree through its bark and trans located throughout the tree leading to its mortality, which usually involves the use of an oil carrier that aids in bark absorption and the extension of treatment times for the species (Gous *et al.*, 2014:5). This aerial method uses a spot application of the herbicide on an individual and precise basis, which has been shown to have minimal damage, less drift to non-target species, minimized chemical usage compared to alternative aerial broadcast methods and reductions in the manpower can be experienced (Throop *et al*., 2013:1; Gous, 2000:7).

The technique has been recognised as the preferred method for searching and controlling scattered or outlier mature Pines that have the potential of spreading large amounts of wind-blown seeds into neighbouring areas of ecological value, while also giving management the added advantage of being able to review areas of past application efficiently visually (Raal, 2016:8-10). The method is preferred at clearing sites, which display these attributes of highly scattered infestation densities present in difficult or inaccessible terrain because such site attributes result in longer walk times to each tree and dangerous working conditions for operators (Raal, 2014:18). The method has been reported to give much more ground coverage compared to previous aerial removal techniques used in similar site conditions, such as skid hopping, which requires operators to exit with chainsaws in difficult terrain while hovering at ground level, causing significantly longer treatment times per tree and dangerous operator working conditions (Briden *et al.*, 2014:371; Gous *et al.*, 2014:5). Deciding factors on when to use this method over ground control are made on an individual basis, but the following factors are considered as shown in Table 2.1 below.

Table 2.1: Deciding factors on when to use ABBA versus ground-based approaches

Factor	Aerial Basal Bark Application	Ground Control Methods
Tree Spacing	Widely Spaced	Closely Spaced
Tree Location	Remote and Inaccessible	Safe and Easily Accessible
Tree Size	<600mm Diameter	>600mm Diameter
Tree Growth Habit	Single Stemmed	Multiple Stemmed

Source: Macalister & Stein (2013:16)

The method however is highly affected by the efficiency of the crew members, and it is advisable that they have aerial application experience, involving an understanding of the aerial mechanics, the chemicals and the knowledge of GPS agricultural systems (Raal 2019:7; Raal, 2012:14). Current ABBA clearing operations recommend either two types of helicopter models, the Robinson R44 and the McDonnell Douglas 500 (MD500), however as shown by Raal (2014:19), there are various advantages and disadvantage between both models, as shown in Table 2.2.

Table 2.2: Comparisons of attributes between recommended ABBA aircraft models

Attribute	Robinson R44	MD500
Power	Limited capabilities in high altitude areas and weight carrying capacity: Cannot hover long enough to effectively treat trees.	Enough power and flexibility to work and hover in high altitude areas with heavier loads.
Rotor Wash	Bigger rotary diameter: Less chemical throwback.	Smaller rotary diameter: More chance of chemical throwback.
Comfort	Less noise and can be shut down with ease.	Noisier: Uncomfortable for operator.

Source: Adapted from Raal (2014: 19)

2.12.2.2 Herbicides used

The scientific literature contains very little information on *aerially* applied herbicides that are effective against invasive Pine species (Raal, 2005:15). Past practices involved using the contact herbicide *diquat* (Donald, 1982:3). However this was proven to be ineffective at controlling the species in their mature growth stages as larger trees can reduce the herbicides impact (Gous *et al*., 2010a:158). It was noted that using *Reglone* on larger wilding conifers would result in mortality of up to eleven months thus requiring monitoring over this time to confirm its complete death (Ray & Davenhill, 1991:22).

Studies on alternative, more effective herbicides were thus identified through trials (Gous *et al.*, 2010a:158), showing young juvenile size classes treated with the selective and systemic herbicides *triclopyr ester* and *picloram*, applied in combination, or a non-selective systemic combination of *glyphosate* and *metsulfuron* gave the best results.

The systemic nature of these herbicides has shown them to be more likely effective as they are translocated within the plant tissues, however when tested on the species at large growth stages they had a lower efficacy (Gous *et al*., 2014: 3-5). Later research (Gous *et al.*, 2015b) thus examined the efficacy of these previous combinations applied at higher rates with wetting agents to enhance uptake, findings showed the aerial broadcast application of *triclopyr* based herbicides applied in a high-volume mixture with large droplets were successful, while tree height didn't affect mortality.

While these previous studies were based on a broadcast/ boom application, little research exists on herbicide formulations for the ABBA method. Studies tested the efficacy of these *triclopyr* based herbicides, with a paraffinic oil used as a carrier at different height classes and results showed the most effective treatments used 1000ml of herbicide, which contained a combination of *triclopyr* and *picloram*, while increasing tree heights decreased mortality rates (Gous *et al*., 2015a; Gous *et al*., 2014).

2.12.2.3 Additional Equipment

The personnel involved in the operation include the spray wand operator and the pilot, while a spray tank that has a maximum capacity of 100 litres of herbicide is connected to a pump, spray tanks can either be placed on the back seat or as a pod on the outside of the helicopter, while the pump operates at a pressure of 4 bars to minimize drift and nozzle damage (Eschenmoser, 2013:7). Spray tanks must have a mechanical agitation system in place to ensure a constant mix of the herbicide during application (Biosecurity New Zealand, 2020b).

Table 2.3 ABBA Additional Equipment

Additional ABBA Equipment		
Small reciprocating pump connected to a 100 litre chemical tank for small metered applications.	A GPS/ flow meter: Gives more effective planning and recording of operations.	A lance/ Wand for herbicde delivery.

Source: Adapted from Biosecurity New Zealand (2020b)

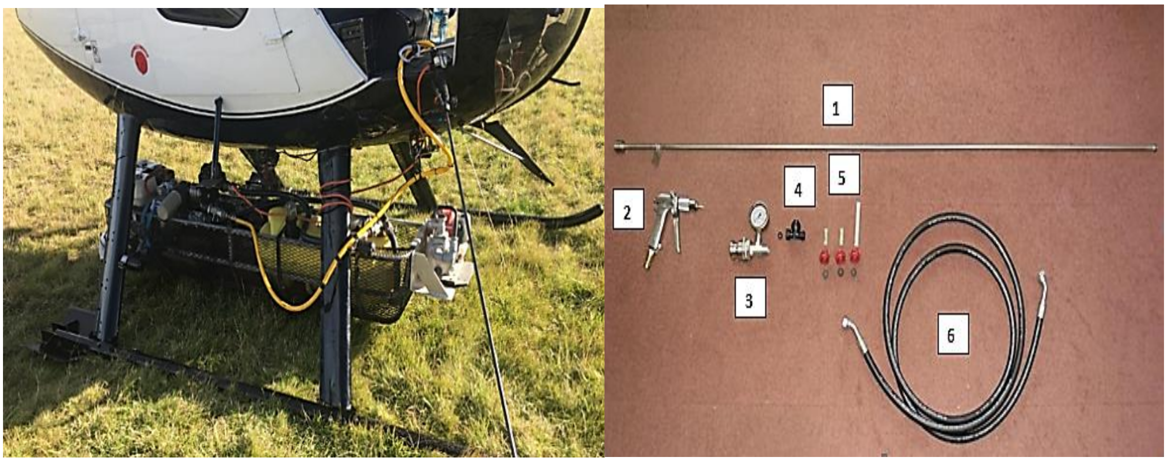

Figure 2.4: ABBA additional equipment placed on underside of aircraft
Source: Credit Howat (Left) and Eschenmoser (2013) (Right)

Figure 2.4 Showing material components for constructing the wand for the ABBA method. The wand consists of: (1) Trigger (2) Nozzle (3) Coupling pressure gauge (4) Tee jet body (5) Nozzle body and (6) Hose.

As explained by Timmins & Braithwaite (2002:311), weed surveillance systems allow infestations to be detected and controlled early, which prevents future escalation of control costs while further minimizing the negative impacts on biodiversity. Sprayed trees can be recorded individually through a ‘Volume and Location GPS Flow Meter’ or a ‘Volume and Location Tool’ (VAL2) which, as explained by the creators Howell & Cockburn (2016:118) comprises of a flow metre integrated with GPS which records the volume and location every time herbicide is dispensed, while additionally providing the search paths taken during operations (Figure 2.5). Advantages of incorporating this surveillance system are shown in Figure 2.6.

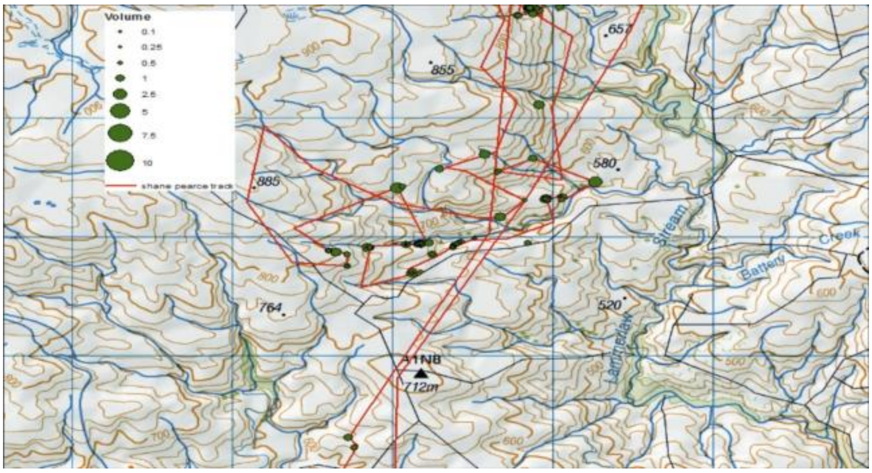

Figure 2.5: Search path (red) and flow rate data (green) as recorded through VAL2
Source: Howell & Cockburn (2016:119)

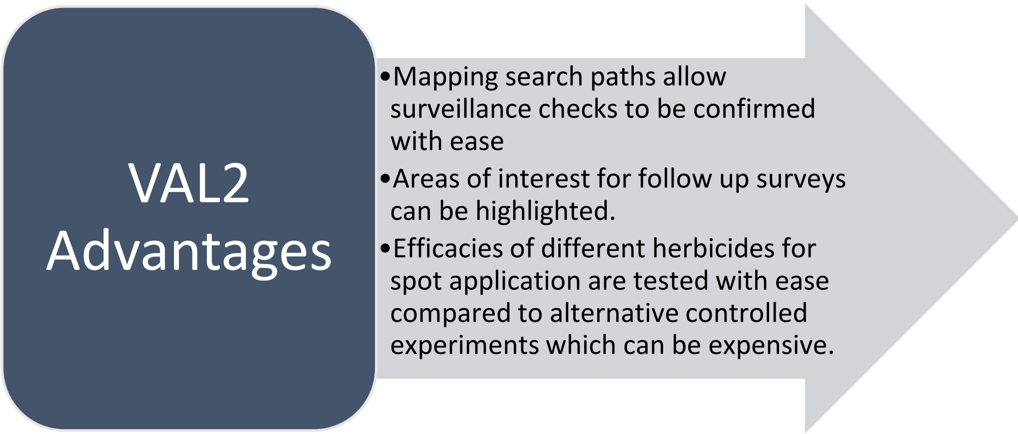

Figure 2.6: Advantages of VAL2
Source: Adapted from Howell & Cockburn (2016)

2.13 Working for Water Information Management System (WIMS)

Alien plant control involves determining how to optimally manage a given infestation, which involves the selection of the distribution of clearing effort through space and time (Baker & Bode, 2016:714). This is achieved through the allocation of 'person days', which can be defined as the amount of time it would take one person to clear a certain task, which is inclusive of the time spent being unproductive such as lunch and rest breaks (Plant Protection Research Institute, 1999, as cited in Ferraz, 2000:29). As explained by Marais (1998:80), clearing effort is related to the number of person days it takes a productive worker to clear one hectare, while non-productive workers such as supervisors or management are not included in the calculation, their costs are however included in the costs per person day.

A major achievement of the WfW programme has been the advent of WIMS in the year 2000, which is based on Geographical Information System (GIS) mapping and implemented in most regions for collecting the spatial information of infestations and generating the needed quotation packages for clearing operations (McConnachie *et al.*, 2012:130; Ground, 2003:9). WIMS has been used over the programmes lifetime to capture and store information on treatment contracts, while using a set of norms and standards to calculate the needed workloads and other resources required for contract formation or generating quotation packages (Working for Water, 2016:4). A graphical representation of this process is shown in Figure 2.7 below. Each component in Figure 2.7 that forms part of the work rate calculation will now be discussed separately in order to provide more detail for the reader.

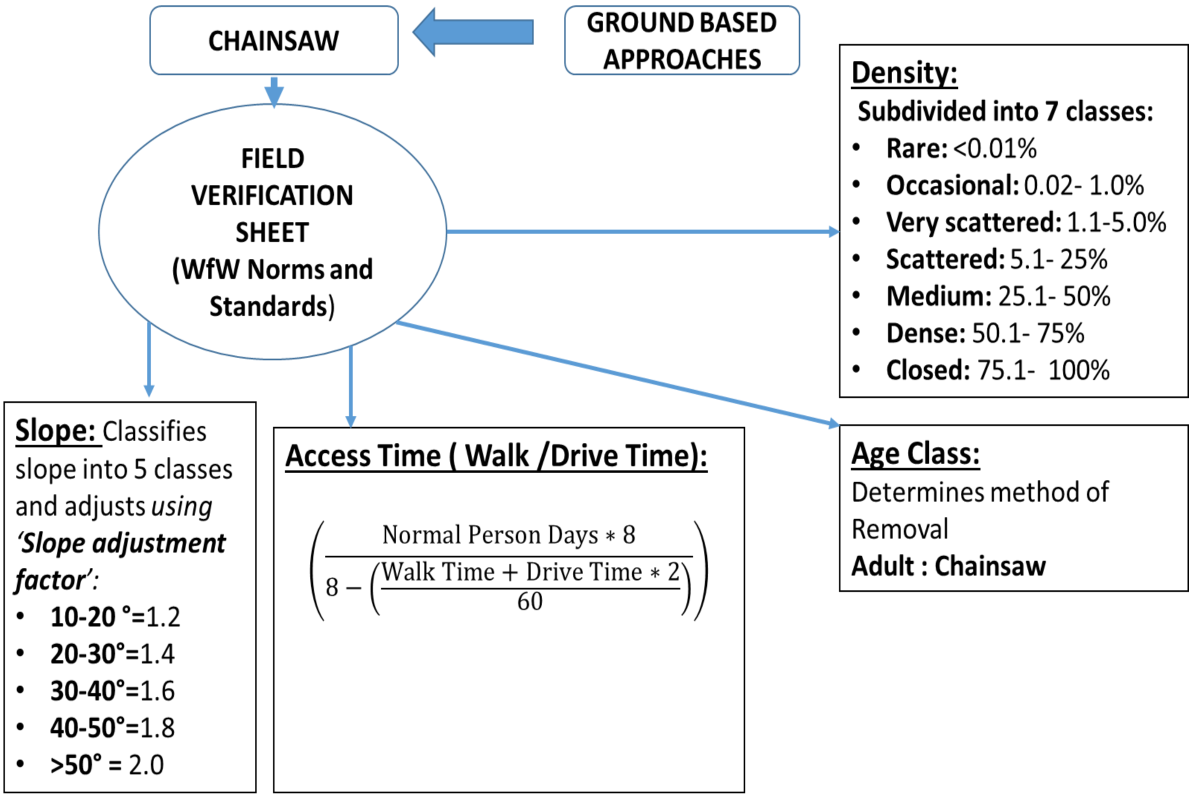

Figure 2.7: Ground based control work rates used in clearing contracts
Source: Adapted from Working for Water Programme (2016)

2.13.1 Species Attributes

Included in the WIMS system are consistent and standardized methods for mapping and describing areas invaded with AIPs, for estimating the costs of clearing which was based on the 'Catchment Management System' (CMS) (Forsyth & Le Maitre, 2018:1). The CMS was firstly developed to produce various spatial layers that assisted managers in defining and identifying boundaries corresponding to physical features easily identifiable at sites using management units or 'compartments' (Le Maitre, *et al.*, 1993:132-133).

The development of these clearing compartment attributes such as density, were however arbitrarily and inconsistently measured, which resulted in the development of a field mapping manual which gave the CMS a consistent means for analysing the most cost-effective control methods using a methodology which effectively mapped for instance: the size, density and maturity of a specific AIP species such as *Pinus* according to a set standard of nationally based classes (Le Maitre & Versfeld, 1994:1-6).

These standards include a table which was developed to allow one to determine the density of a site based on the plants size, age or number of plants or stems per hectare, while being able to make approximate conversions between them (Le Maitre & Versfeld, 1994:6). Densities are presented in seven classes and are recorded by WFW in percentage canopy cover (Working for Water, 2016:16-18), as shown in Annexure C. It was however noted that higher amounts of smaller trees can fit in a hectare compared to larger sized ones and different species can occupy more space compared to others (Le Maitre, personal communication, 2019). This was solved by classifying species into different size classes: Seedling, young, adult, and grouping them into different growth forms: tall shrubs, medium trees and tall trees, while tree size and species determines the method of removal. To generate the contracts for clearing, WIMS uses information given by WfW project managers which is then measured against pre-determined norms and standards to determine the amount of person days needed to clear a specific clearing unit known as an 'Natural Biological Alien Land Cover Attribute' (Nbal) (Levendal *et al*., 2008:39-41). The characteristics of the different clearing units or 'Nbals' are used to estimate the workloads or person days for drawing up the contract prices needed as a basis for negotiation between the various contractors willing to undertake the clearing operations (Neethling, personal communication, 2019). Person days can further be separated into 'normal person days' and 'adjusted person days' as explained below.

2.13.2 Physical Attributes

Work rates for different clearing units or Nbals are calculated by contractors and translated into normal person days per hectare, such that the following factors are identified and recorded on each clearing unit as having an effect on the overall time to clear for calculating normal person days (Neethling & Shuttleworth, 2013:4).

These are recognized as:

- Species Type (aquatic, herbaceous, sprouting, non-sprouting)
- Size of species (seedling, young or adult)
- Control done in either a landscape or riparian area.
- Control Method (felling, ring bark etc.)

Control methods selected are dependent on various factors such as the plants' size, age and growth form (Cacho *et al.*, 2008:562). Most treatment approaches therefore take into consideration the specific type of AIP to be cleared, as major differences in workloads and costs can occur between species, even when dealing with alien tree species specifically. Their removal method is selected based on its size and its ability or inability to re-sprout after the initial treatment has taken place, for example Acacia require higher workloads to clear compared to non-sprouting species such as Pinus

(Marais & Wannenburgh, 2008:536) The size or age of the species (seedling, young or adult) is also taken into consideration in work rates as larger mature trees can increase treatment costs significantly, for example by adding more to the time of removal when compared to smaller plants (Marais, 2000:12).

The starting point in calculating the normal person days of a clearing unit, is firstly knowing the AIP species type and its age class, which determines the method of removal (Neethling, personal communication, 2019). The consideration of whether control is either done in a landscape or riparian areas is due to riparian areas requiring materials to be carried 30m away from waterways which further adds to the work rate. Adult trees in riparian areas are normally 'killed standing' due to the difficulty of removal.

Once these variables have been considered WfW then allocates a specific amount of person days per hectare to clear, based on a condensed infestation density of 100% using the norms and standards. This condensed hectare, person day value is then modified downwards at one percentage increments according to the actual density of the infestation.

Other than calculating normal person days as described above, management can further modify these normal person days into estimated 'adjusted person days' which takes into account the 'physical site attributes' of a clearing site which include slope, driving and walking time and the influence of surrounding obstructive vegetation density (OVD), whereby OVD although recorded, there is currently no effect on work rates at present which has been highlighted as an important need to be considered going forward (Working for Water, 2016: 20:24).

2.13.2.1 <u>Slope</u>

Slopes in clearing areas is an important aspect to account for, and can increase work rates and costs, as rugged and mountainous areas with steep slopes or cliffs can increase access times and movement within these areas, while in some cases requiring additional rope work skills and safety precautions (Forsyth *et al.*, 2016:8). As previously mentioned, the Pinus species are also most prevalent within these high-altitude areas.

The average slope is recorded in degrees and measured in three ways (digital elevation model in ArcGIS, survey equipment and visual estimation) and a slope adjustment multiplication factor is added which corresponds to a specific slope degree which is represented by six classes (Forsyth & Le Maitre, 2018:35). These slope classes are shown in Table 2.4 below:

Table 2.4: Working for Water Slope Adjustment Factors

Slope Class	Slope Range (Degrees)	Multiplication Factor
S0	0-10	1
S1	10-20	1.2
S2	20-30	1.4
S3	30-40	1.6
S4	40-50	1.8
S5	>50	2.0

Source: Adapted from Forsyth & Le Maitre (2018: 35)

2.13.2.2 Accessibility: Walk and Drive Time

Drive time is defined as the time from the pickup to project site, while walk time is defined as the time taken to walk from the nearest drop off point with vehicle access to the centre of the Nbal (Working for Water, 2016:22). The walk or drive time taken in getting to a clearing time site can cause work time to be lost and thus decrease the amount of available time operators have for undertaking clearing work during the day (Wise & Coetzee, 2001:2). Accessibility can especially become a major component of costs when dealing with remote clearing sites as workers and equipment must reach the area (Harris & Timmins, 2009:11). Amongst other prioritization factors, clearing operations within the study area that have been within an approximate distance of 3km of the nearest road have been given higher priorities as at this distance it takes clearing teams a time of two hours to reach a clearing site in rough terrain with the heavy equipment (Jacobs *et al.*, 2017:95). Accounting for the effects of walk and drive time on work rates is accomplished by deducting the amount of access time from the person days or the available time people can work within a standard 8-hour shift (Neethling, personal communication, 2019).

Equation 2. 1: Walk and drive time effects on original site clearing times

$$\left(\frac{NPD * 8}{8 - \left(\frac{WT + DT * 2}{60}\right)}\right)$$

Where:

NPD= Normal Person Days

WT= Walk Time

DT= Drive Time

Initially, to get the total access time, both factors are added in minutes and multiplied by a factor of two to account for return trips. The total commuting time is then converted into hours and further subtracted from an eight-hour working day to get actual available working times after accessing a site. Finally, the NPD in hours is divided by the actual working time which increases the person day amount. Person days are adjusted upwards by dividing the NPD by the actual work times on the site (Working for Water, 2015: 36).

2.13.2.3 Surrounding Vegetation Density

Costs of control operations can increase with increases in surrounding vegetation density, as searching becomes more difficult (Harris & Timmins, 2009:13). Vegetation as described by Campbell *et al* (2019:3) is the presence, abundance, and arrangement of physical impediments on top of the ground surface. Vegetation effects travelling over heterogeneous natural environments by impeding movement in various ways, such as 1) having to physically alter the desired path through branch and stem breaking, 2) obstacle avoidance by stepping over low fallen debris or higher stronger denser patches which force route deviation or redirection and 3) friction from biomass which resists forward movements (Richmond *et al*., 2015:20; Campbell *et al*., 2019:3).

Using a scoring model to estimate a summed 'impedance value' which effects the effort to achieve eradication, Panetta & Timmins (2004:8) included the vegetation type as a factor impeding work rates. Using these impedance values, Cacho *et al (*2006:903-909) later incorporated detectability into a population model, which showed that one of the variables having the greatest effect on the duration of eradication efforts, was an individual's search speed, which can depend on the density of vegetation. Locally adapted studies in South Africa have been scarce but have involved work done by Goodall & Naudé (1998:113), where vegetation was categorised on its potential to impede operations using three classes with corresponding weightings: short/open (X1), open to closed (X1.4) and thicket (X2). Using the same weightings, Ferraz (2000:46) chose the density of American bramble (low, medium and dense) to reflect penetrability in Kwazulu-Natal as the weed species most likely to impede operations. It was however mentioned by these authors, that one of the possible disadvantages, was that a work rate study was not undertaken.

Other studies on the effects of surrounding vegetation on work rates have been studied in other fields such as wildfire risk analysis for determining an individual's travel rate against a fires spread rate such as fire-fighter escape route planning through field experiments undertaken by Alexander *et al* (2005:4), which showed open fuel types such as grassland and logging slash gave faster travel times compared to spruce fur stands with dense understories. A recent study using airborne lidar remote sensing technology, derived a range of vegetation conditions and their effects on travel times which showed areas dominated by dense sagebrush or juniper reduced travel times by 22% and 23% respectively (Campbell *et al*., 2017:894).

2.13.3 Costs

After a specific number of person days are allocated to a given Nbal the contractor costs are then calculated, which can be described as the costs paid to the contractor to complete the control of an infestation within a specific Nbal. As explained by Loftus (2013:18) contract costs include all the costs covered in a quotation package for a contractor, which includes the total wage cost to clear a site, the Unemployment Insurance Fund (UIF) contributions, camping costs, personal protective equipment (PPE), tools and equipment, administration and so forth, as set out in Table 2.5, and further shown in Annexure D. The costs of overhead management are however excluded in these direct contractor costs and past studies measuring the historical clearing costs of AIPs in the CFR (Van Wilgen *et al.,* 2016:170-171) have accounted for these by adding an overhead cost of 32.5% on these direct clearing costs as this was the mean amount both Cape Nature and SANParks levy on direct costs across their protected areas. The costs of herbicide are also not accounted for in these direct contractor costs and other past studies have also added this component to these direct costs (Van Wilgen *et al.*, 2012:30).

Table 2.5: The individual direct contract cost components

Cost Categories Included in Clearing Quotation Packages
Total Wage Cost to clear the Site
Unemployment Insurance Fund
Rations/ Camping Allowance
Personal Protective Equipment
Tools and Equipment
Transport
Administration
VAT (15%)

WfW therefore follows a contractor development approach task-based system, whereby beneficiaries are compensated on completion of a clearing site and according to legislation, AIP clearing is undertaken by contractor teams which consists of 11 productive team members and the contractor, who competitively tenders to clear a site (Buch & Dixon, 2009:133; Hough, 2010:38; Hough & Prozesky, 2013:2). Contractors must follow the initial standard WfW clearing teams, as set out by the WfW norms and standards for normal teams (Neethling and Shuttleworth, 2013:4) (Annexure E), as these clearing team compositions are used by project managers to set a 'benchmark price' for clearing, in order to generate quotes which are measured against the prices quoted by contractors (Working for Water, 2015:4). Contractors receive support from project managers until they are able to develop the required quotations for clearing, that comply with the programmes' clearing work rate norms and standards, health and safety standards and other employment conditions for workers (Morokong *et al*., 2017:277). Compared to normal teams, no such norms and standards exist at present for high altitude teams (HATs) (Paulsen, personal communication, 2019).

2.13.4 Limitations on Work Rate Variables

Prioritizing clearing operations involves allocating scarce resources to maximize returns; one component that is necessary to achieve this is to include detailed costings realized from current removal methods (Kettenring & Adams, 2011:971). Although there have been attempts at prioritizing areas for management at national level (Robertson *et al*., 2003:37; Nel *et al*., 2004:53, Blanchard *et al*., 2015:1) and at finer scales (Van Wilgen *et al*., 2008:336). Prioritizing conservation actions based on the consideration of economic costs however have been rarely found in prioritization plans which are largely focused on biological values (Moore *et al*., 2004:343).

While biological values are important, they are not the only aspect which should determine the prioritization of conservation activities. Planning which aims to maximize cost efficiency by integrating the heterogeneous costs into the planning process has potentials in leading to significant increases in the cost effectiveness of conservation planning (Moore *et al*., 2004:343; Naidoo *et al*., 2006:681).

Past prioritizations for clearing at operational level, for example, have dealt with workload or ease of control based on the species biological aspects by examining its seed bank longevity and re-sprouting ability. Local conditions such as a sites accessibility and surrounding vegetation were recognized as having potential effects on work rates. These conditions were however excluded from prioritization planning due to a lack of detailed information currently available (Blanchard *et al.*, 2015:14).

In addition, although past studies have shown surrounding vegetation density to be one of the most important components affecting one's ability to efficiently move through an area, having larger effects on travel times compared to slope (Campbell *et al.*, 2017:894).Although surrounding vegetation density is recorded in WIMS, there presently exists no actual work rate or person day adjustments made for this factor in the system and as such is excluded in work rate calculations (Le Maitre, personal communication, 2019). As noted by practitioners, this can especially be the case in areas of the mountain fynbos which mostly comprise of un-burnt vegetation whereby operators walk times have taken significantly longer to the next tree, especially when distances to the next tree are longer as in sparse infestations (Paulsen, personal communication, 2019).

Decision tools that involve the prioritization of woody IAPs based on their various environmental complexities which vary from site to site and at scales that aid the co-ordination of on the ground management has thus been recognised as area of need (Roura-Pascual *et al.*, 2009:1601-1603).

One such changing environmental complexity which would help in management decision making would be to include the varying surrounding vegetation at clearing sites and incorporate its effects on the work rate or person days.

2.14 Conclusion

Chapter 2 highlights that current alien invasive pine clearing methods are too slow and not having the desired results in terms of clearing the species and as a result are spreading uncontrollably. This is especially the case within the rugged and inaccessible areas where current clearing methods are ineffective. Biological control could have provided an effective solution for the control of the species, however due conflicts of interest taking place this has been prevented. There is therefore a need for alternative approaches. One such approach is in the form of novel control methods which are showing promise in other countries dealing with the species which have improved the efficiency and scope in dealing with the species. Two novel based approaches were presented and discussed as to provide some familiarity for the reader when these methods are incorporated into the model in later sections. Alien invasive pine clearing operates within a complex environment as a sites physical characteristic can vary considerably from site to site which makes it particularly difficult for managers to select which clearing method would be the most financially favourable option under the physical characteristics of a clearing site. These various site characteristics can vary in the form of tree density, slope, walk time and drive time and control method. The chapter thus gave the reader an in-depth discussion on how these various site characteristics are measured to determine the amount of time needed to clear on site which would give a basis on how these components were then adjusted to conditions of the study area in Chapter 3.

Chapter 3: Model Development

3.1 Introduction

To effectively address the research aims and objectives, the methods or model development were divided into three sections: work rate modelling, application of model to ground based methods and application of model to the ABBA method. The work rate and cost data used by national alien clearing programmes was taken as a starting point for the chosen ground methods, while close consultation was undertaken in developing the needed work rate and cost data for the chosen novel-based methods through personnel currently pioneering and using these novel methods in New Zealand.

3.2 Study Area

The Western Cape Province of South Africa, which is comprised of five of the nine vegetation biomes in Southern Africa: The Fynbos, Forest, Albany Thicket, Nama, and Succulent Karoo Biomes. The Fynbos and Succulent Karoo biomes form most of the area of the province (Rutherford *et al*., 2006:33). The Fynbos biome contains the highest number of species with the greatest proportion of them being endemic (Russell, 1987:217).

Two areas within these biomes: The Succulent Karoo and the CFR have been named biodiversity hotspots (Myers *et al.*, 2000:854). The CFR includes five of these biomes and occupies about 90 000km^2, housing 8600 plant species of which 68 percent are endemic (Bond & Goldblatt, 1984, as cited in Linder, 2005:536). The region is comprised of rugged topography with slopes from 0° to over 40° (Campbell, 1983:285) and vertical landscapes with exposed cliffs which offer a greater habitat diversity compared to its lowland regions (Goldblatt & Manning, 2002:283). The region is also characterized by a Mediterranean type climate (cool wet winters and warm dry summers) with a fire prone and adapted ecosystem for sustaining its diversity (Van Wilgen *et al*., 2010:632). The study area has become heavily invaded by woody AIPS whereby Pine (*Pinus spp.*) and Hakea (Hakea *spp.*) have had wider distributions into large tracts of mountain catchments in reaction to fire (Van Wilgen, 2009:338) while the latter species are additionally sourced from adjacent plantations where they provide various economic benefits throughout the region.

3.3 Work Rate Modelling

3.3.1 Introduction

Work rates applicable to ground control methods have been developed by national clearing programmes. It was necessary, for the purposes of this study, to develop these work rates further since they were not originally designed to consider specific work rate variables for the chosen study area. These work rates were taken as a starting point and then developed further from consultation with operational personnel with the most experience in the field. Cost data was extracted from national clearing programme data for the ground-based methods. For the novel based methods, since these methods are novel in nature and no such work rates or costing data exist at present nationally, consultation was undertaken with personnel pioneering these methods in New Zealand. Costing data was adapted for conditions of the study area with reference to current national clearing data to produce a workable model. The model will now consider all possible attributes affecting the work rate to compile the work rates at these different combinations in a work rate table matrix.

3.3.2 Adaption of Work Rate Variables

In Chapter 2, the following four factors have been identified in national clearing operations (Working for Water, 2016) as having an influence on work rates or clearing times:

- Density
- Slope
- Obstructive Vegetation Density (OVD)
- General Accessibility: Walk time and Drive Time

The work rates used by WfW (Neethling & Shuttleworth, 2013) were used as the basis for this research. The following adaptions were however made due to the characteristics of the study area:

3.3.2.1 Density

As explained in earlier sections, the WfW mapping standards can be used to determine the infestation density of a site, while also giving one the ability to make approximate conversions between certain species, plant size, age or number of stems per hectare at each density class (Le Maitre & Versfeld, 1994:6).

Firstly, it was decided for the purposes of the study, instead of using the original range of density cover classes for the invasive species according to the WfW mapping standards, each of the seven classes were adapted according to their individual midpoint densities. These midpoint densities are also used in practice in recently developed management unit control planning (MUCP) software used by WfW for evaluating the feasibility of AIP removal according to available budgets throughout the study area (Forsyth & Le Maitre, 2018:56). Additionally, each of the seven-midpoint density percentage cover values was converted to their equivalent stems or plants per hectare count. The midpoint cover percentages of each of the seven density classes along with their corresponding number of plants per hectare are shown in Table 3.1, which were both adapted from the WfW mapping standards (Le Maitre & Versfeld, 1994:6).

Table 3.1: Midpoint Cover Classes

Density or Abundance Class (D)	Species Cover Range (%)	Midpoint Cover (%)	Equivalent Plants/ha
D1: Rare	<0.01%	0,01	0.5
D2: Occasional	(0.02%-1.0%)	0,51	19
D3: Very Scattered	(1.1%-5%)	3,05	121
D4: Scattered	(5.1%-25%)	15,05	754
D5: Medium	(25.1%-50%)	37,55	2620
D6: Dense	(50.1 %-75%)	62,50	5722
D7: Closed	(75.1%-100%)	87,55	9930

3.3.2.2 Slope

Accounting for slope can be accomplished by dividing slopes into various gradients with corresponding weightings or 'slope' factors (Goodall and Naudé, 1998:113). Current national AIP clearing programmes also account for slope using this same aforementioned methodology (see Chapter 2). Initially the model used the same weightings currently used in national clearing programmes, however it was later discovered these slope calculations would directly affect the access factors outside the site such as walk time and drive time. It was thus decided for purposes of the study to use the same methodology used by Cheney (2019:199), and keep these factors separate by accounting for the effects of slope as an increase in the surface area to be cleared in relation to a flat surface.

The effects of an increase in surface area to be cleared relative to a flat surface, as explained by Cheney (Personal communication, 2020) would thus have the following two effects on the model: an increase in both the total number of plants to be treated and the total walk area, while factors outside of the site such as walk time and drive time are kept separate.

3.3.2.3 Walking and flying time between trees

Ground Based Control: Obstructive Vegetation Density (OVD)

To capture the effects of OVD on the present work rates, the operational specialists who constructed these current work rates and who have the most knowledge and practical experience in their use were consulted (Neethling, personal communication, 2019; Shuttleworth, personal communication, 2020). Based on these consultations it was agreed that to account for the variables effects on work rates one would need to create three theoretical density or OVD penetrability factors: Slight (OVD1), Moderate (OVD2) and Dense (OVD3).

American Bramble has been identified in past studies (Ferraz, 2000:44) as a weed that significantly impedes AIP control and slows down clearing operations and the species has been chosen to reflect penetrability according to three categories: Low, Medium and Dense and corresponding weightings (Goodall &Naudé (1998:113). Shortcomings however as mentioned by both Ferraz (2000:80) and Goodall & Naudé (1998:113) was that no work rate studies were done to validate these factors. A work rate study done by Neethling & Shuttleworth (2013:12) gave the cycle time of an individual worker foliar spraying young American Bramble at an observed 60% density, where other than the bramble, the workers' movement was not restricted by other obstacles and the study was undertaken in open grassland with spraying done in lines instead of random movements. The work rate study showed it took an individual worker in these conditions 2.80 minutes to change their position to spray in an area of 1190m^2 (0.119 hectares) which could be directly extrapolated to a total time of 23.50 minutes per hectare for a worker to change position under these conditions, which was later confirmed (Shuttleworth, personal communication, 2020). It was decided to use this time of 23.50 minutes to change position in 60% bramble to represent the 'Dense' penetrability factor. Using this verified time from the dense OVD class, the moderate and slight OVD factors were reduced by a conservative value of 40% and 60% of this original value respectively, which gave the following values as outlined in Table 3.2.

Table 3.2: Obstructive vegetation density (OVD) factors

Obstructive Vegetation Density Factor (% Bramble Density)	**Description**	**Penetrability Factor (Minutes/hectare)**
SLIGHT (OVD1): 40% of OVD3	Slightly hindered mobility, some extra effort is required to move through the veld. Free walking is however still possible but somewhat affected.	9.41
MODERATE (OVD2): 60% of OVD3	Hindered mobility and noticeable effort is required to move through the veld. Walking is still possible but slow.	14.12
DENSE (OVD3): 60% Bramble Density	Difficult mobility, considerable extra effort is needed to move through the veld. Climbing/crawling through the vegetation is required.	23.53

It must be noted that although the "Slight" and "Moderate" OVD factors were not directly extrapolated as the "Dense" OVD factor, the direct extrapolation of the "Dense" OVD factor from the work rate study gave a good starting point. It would have been more desirable to have more work rate information on the effects of these factors on work rates but after an extensive literature search, other than work done by Ferraz (2000:80) and Goodall & Naudé (1998:113) there is little information on such work rate studies existing nationally and involving AIP control. It must also be noted American Bramble (*Rubus cuneifolius*) is not common in Western Cape clearing operations but in areas such as Kwazulu- Natal where the species affect AIP workers movements significantly (Ferraz, 2000: 42-44), however this was the closest species that one could find which related to an actual work rate study and related to AIP clearing nationally at present.

Drill and Fill Walk Time

During the study, managers currently pioneering the method in New Zealand were consulted and it was mentioned, that a significant advantage the drill and fill method has in the field is the lighter weight of the drill equipment compared to a chainsaw, allowing operators to walk faster through surrounding vegetation (Raal, Personal Communication, 2020). After an extensive literature search no such quantitative data on these times currently exist. It was therefore decided that to account for this important difference in walk times for the drill and fill method, a 25%, 30% and 40% reduction in walk time was added on the original slight, moderate and dense penetrability factors respectively as previously shown in Table 3.2.

Aerial Basal Bark Application

It was assumed that the effects of OVD would not be present on the ABBA method, however the rate at which the aircraft could cover a hectare was needed. Based on the benefits of using the MD500 aircraft as outlined in Chapter 2, it was assumed this model aircraft would be used during the operations. Based on a study by Leary *et al* (2013:297) using herbicide ballistic technology for targeting incipient Miconia (*Miconia calvescens*) in extreme topography of Hawaii's watersheds using a MD500 helicopter (Figure 3.1), it was estimated it took the aircraft a minimum of 1.13 minutes to search a hectare in the study area when no species were detected. It was thus decided to use this time to represent the aircrafts flying time per hectare at zero percent canopy cover which was then scaled down according at each of the midpoint cover percentages to represent the overall flying time between trees at each combination. It must also be noted that this search time at zero percent density can be a conservative estimate as noted by the authors (Leary *et al*., 2013:299) Miconia detectability was impeded by heavy vegetation and extreme topography and the location of the species was unknown thus requiring longer search times. *Pinus* are more noticeable in the landscape and if their whereabouts are also known beforehand this can possibly result in lower search times compared to the Miconia species.

Figure 3.1: Operator targeting incipient Miconia using Herbicide Ballistic Technology.
Source: Leary et al (2013)

3.3.2.4 Walk Time and Drive Time (Accessibility)

For the purposes of this study, walk time was defined as beginning from the nearest road to the centre of the Nbal while drive time was measured from the project office to the nearest road or drop off point to the Nbal. This assumed a standard workday shift consisting of eight hours. To make the effects of accessibility comparable to that of the aerial method later in the study, it was decided to make the walk distance from the nearest road to the centre of the Nbal 3km which would result in a travelling time of two hours one way in rough terrain. This was based on Cape Nature's prioritization of clearing compartments where accessibility has been recognised as directly affecting clearing costs, such that sites within 3km of the nearest road are given higher priority as this is the approximate distance clearing teams can manage to walk in two hours with heavy equipment in rough terrain (Jacobs *et al*., 2017:95). This walk time was therefore assumed as the 'difficult' walk time scenario for ground teams in rough terrain which equated to a walk speed of 1.5km/hour over this distance. A study by Van Wilgen *et al (*2016:171) assumed a walk speed of 3km/h from the nearest road to the centre of the Nbal, and thus this walk speed represented the 'Easy' walk time scenario which would therefore take ground teams a total time of one hour to transverse the assumed 3km distance one way. In order to account for the faster walk speeds that have been recognised in practice from the lighter drill equipment compared to a chainsaw (Raal, personal communication 2020), it was decided that these aforementioned walk times to the site would be reduced by a conservative 10% for the drill and fill team to represent these faster walk times to the site.

It was assumed drive time would be based on a total average drive distance of 30.28 km (excluding return trip). This total average distance was based on the individual one-way drive times from the project office to the nearest road of each Nbal as extracted from WIMS Western Cape Nbal physical data. Nbals only containing drive time (n =21,530 entries) were selected which gave a mean drive time of 30.28 minutes. This aforementioned data was however only presented in time and thus using the study by Van Wilgen *et al* (2016:171) which assumed a driving speed of 60km/h for ground teams gave an average one way driving distance of 30.28 km.

Using the same methodology utilised by WfW clearing contracts as explained previously in Chapter 2 for calculating the effect of access times on normal work rates, the 'Easy' and 'Difficult' accessibility scenarios were instead converted to their specific 'distance factors' using the same method as in previous studies (Ferraz, 2000:47; Goodall & Naudé, 1998:113) whereby actual work time on site is divided by the 8 hour working day giving the same resulting increase in work rates. It must also be noted that walk and drive times as in Table 3.3 are quoted as round trips meaning return trips have been accounted for and added to each component while the 30km drive distance was added to both the 'Easy' and 'Difficult' walk time scenarios.

Table 3.3: Calculation of distance factors

Walking Difficulty	30km Drive Time (Hours)	3km Walk Time (Hours)	Actual Work Time (Hours)	Factor Increase on Work Rate
Easy	1	2	5	8/5 = 1.6
Difficult	1	4	3	8/3 = 2.67

3.3.2.5 High Altitude Teams (HATs)

It has been recognised in practice that slope directly affects the cost of clearing, as the steeper the slope the more specialized the teams must be, and thus the more expensive the clearing (Jacobs *et al*., 2017:95). Such reasons being that steep areas are difficult to work in especially when carrying the equipment for removing large trees such as Pines (Forsyth *et al*., 2016:8). HATs additionally require specialized rope and safety skills along with specialized equipment such as ropes and harnesses which make it more costly compared to normal teams (Van Wilgen *et al.*, 2016:171). It was thus decided to try to capture the differences in costs cleared by HATs in these steeper sloped areas. Currently no such norms and standards exist as with normal teams and as such discussions were undertaken with Working on Fire (WoF) ground operations managers for HATs (De Smidt, personal communication, 2019) and specialized rope access team (SRAT) managers (Leukes, personal communication, 2019) who operate within the same areas.

It was decided these high angle areas would be defined as those with slopes ≥40°, as at this point it becomes too unsafe for normal teams without the required rope and climbing skills (De Smidt, personal communication, 2019; Leukes personal communication, 2019). Further consultation with the literature showed the same slope cut off points were used by Van Wilgen *et al* (2016) to account for these HATs in the CFR while WfW's strategic spatial plans for HAT operations within the Western Cape prioritised HAT operations at slopes of equal to or more than 40° (Department of Environmental Affairs, 2015:3).

3.4 Overall Structure of the Model

3.4.1 The Work Rate Matrix

3.4.1.1 Total area invaded and treatment time

For each of the seven midpoint percent cover classes their equivalent total condensed area or ‘condensed hectare’ value was calculated using the formula as described by McConnachie *et al* *(*2012:130):

Equation 3. 1: Total area invaded

$$C = d/100 \times \mathrm{A}$$

C represents the area expressed in condensed hectares, d is the percentage canopy cover and A is the area in hectares that was treated. It must be noted that, for the study's purpose, A instead represented the 'sloped area' as a change in each of the various slope classes would increase A accordingly and thus increase the original condensed hectare value.

While this equation gave the corresponding condensed hectare values at each of the seven midpoint cover classes, however one still needed to get the total treatment time per hectare at each of the midpoint cover class and slope combinations. The number of plants that could be treated per shift was calculated using the following formula:

Equation 3. 2: Plants treated per shift

$$Ps = Ts/Tp$$

The number of plants treated per shift (Ps) depends on the available treatment time (Ts), which was assumed to be 410 minutes in a standard 480-minute shift after non-productive allowances were considered (Neethling & Shuttleworth, 2013:1-2) between all methods, and the assumed treatment time per plant in minutes (Tp) which was dependent on the specific method which will be provided in later sections. After Ps was calculated for each of the three methods, the amount of treatment time was then calculated for each method using Equation 3.3. below:

Equation 3. 3:

$$Tt \ = Cp/Ps$$

The treatment times for the method (Tt) was measured in person days for the felling and drill and fill methods, while presented in hours for the ABBA method which could then be scaled down at each midpoint cover classes between all the methods using Equation 3.1 previously discussed. Cp is the equivalent number of plants at a condensed hectare which was the same for all methods and was achieved by converting a condensed hectare at 100% cover to plants/ha using the WfW mapping standards (Le Maître & Versfeld, 1994:6), which gave an equivalent amount of 12430 plants/ha in a condensed hectare.

Using the above equations resulted in one being able to get the corresponding treatment times per hectare at each of the various slope and midpoint cover classes between the various methods. It must be noted that for purposes and throughout the study, the treatment time component would be instead represented as 'felling time' for the chainsaw method and 'tree poisoning time' for both the drill and fill and ABBA method respectively.

3.4.1.2 Total walking area and walk time between trees

Although the above work rates could be calculated based on national clearing work rate data, the walk time component is however absent in measuring costs of clearing data (Le Maître, personal communication, 2019) while also limited studies have been done in the study area in incorporating this component on work rates. Search area was defined as the area not covered with AIPs and the equivalent search area was calculated at each midpoint percent cover class as follows:

Equation 3. 4: Walk Area equation

$$((100 - d))/100 \times A$$

Once the walk area in hectares was calculated at each midpoint cover class, walk time would need to be calculated at each of the three OVD factors for the ground-based methods.

Equation 3. 5: Walk time (PDs) Equation

$$Walk\ time\ (Person\ Days) = Walk\ Area(\ Hectares) \times\ (OVD\ Factor)/(60\ /\ 8)$$

Using Equation 3.4 and 3.5 gave the equivalent walk time for a clearing team at each midpoint cover class and OVD factor. This component was also calculated for the ABBA method; however, this was referred as 'flying time' such that the OVD factor was replaced with 'flying time' as explained previously.

3.4.2 Costs

3.4.2.1 Ground based Control Methods

The purposes of the study was to achieve a cost per person day, therefore all the cost components: the wages, equipment and PPE would thus need to be presented into a 'daily rate'. When referring to ground team costs as explained in Chapter 2, costs include the amount of South African Rands paid directly to the contractor which include the total wage cost to clear the area, UIF, rations/ camping allowance, PPE, equipment, administration and so forth (Annexure D). These former costs can be described as direct labour and equipment costs (Loftus, 2013:33-34). These direct contractor costs exclude other cost component such as herbicide and management overheads and it was thus decided to add management overheads to these costs, with the addition of the herbicide cost for the drill and fill method.

3.4.2.2 PPE and Equipment

Team members within the normal team composition would be fulfilling different clearing roles and thus specific PPE and equipment items for each job type would be needed. WfW provides this in their PPE, tools and equipment lists per specific job type, along with their relevant quantities and lifetimes of each item for normal teams as shown in Annexure F. WfW quotation guidelines (Working for Water, 2015:6-7) calculate each equipment and PPE items ‘daily rate’ in each specific job type as shown using Equation 3.6 to get a total equipment and PPE daily rate for each item based on 186 working days per year.

Equation 3.6: Equipment and PPE daily rate calculation

$$Daily\ Rate\ = (Price\ of\ Item\ \times\ Quantity)/(Lifetime\ in\ Years\ \times\ Working\ Days\ Per\ Year)$$

Source: Working for Water (2015: 6)

These WfW PPE and equipment lists, and daily rate calculations were therefore used as a basis in determining each item needed per specific job type, along with their relevant quantities and lifetimes. The unit prices of each of these items were obtained from WfW operational spread sheets which were originally presented in 2015-year values and therefore for the studies purpose were inflated to current year prices using a CPI index. Using this aforementioned information, a total daily equipment and PPE rate was calculated for each job role and consolidated in Excel (Annexure G). These total daily rates were then used to calculate a clearing team’s total daily team rate according to a specific team composition inputted in the model.

The drill and fill method, as mentioned previously is a novel method, and as such the necessary PPE, and equipment were obtained from New Zealand best practice guidelines and prices for specific and general items were obtained from local suppliers within the area and taken from the WfW operational spread sheets respectively.

A ‘total daily team rate’ was then calculated based on chosen team compositions for both methods. Standard normal chainsaw clearing team compositions were assumed for the chainsaw clearing teams as in Annexure E. It was however decided, for the study’s purpose, to replace the herbicide applicator with a general worker as previously mentioned in Chapter 2, the *Pinus* species are non-coppicing and thus don’t require herbicide application after felling (Table 3.4).

As explained earlier, standard team compositions for HATs were constructed based on discussions with WoF ground operations managers for HATs (De Smidt, personal communication, 2019) and SRAT managers (Leukes personal communication, 2019) as shown in Table 3.4. It must be noted that health and safety workers, first aiders and peer educators within normal teams can be classified as general workers as they have the same daily PPE, equipment, and wage rates. The same can be said for HATs as health and safety workers and first aiders have the same daily rates as rope access technicians (RACs) (De Smidt, Personal Communication, 2019). It was also discovered that clearing teams can have a maximum of 13 productive workers, while chainsaw operators must be supported by at least two general workers for health and safety purposes (Leukes, personal communication, 2019). Based on this aforementioned information, this would therefore result in a maximum of four chainsaw operators that can be accommodated within the maximum productive worker limit.

Table 3.4: Assumed Normal and High-Altitude Chainsaw Team Compositions

Normal Team Composition	High Altitude Team Composition
1 x Contractor or Supervisor	1 x Contractor or Supervisor
1 x Chainsaw Operator	1 x Chainsaw Operator
6 x General Workers	8 x Rope Access Technicians
1x Health and Safety Worker	1 x Health and Safety Worker
1 x First Aider	1 x First Aider
2 x Peer Educators	

As explained previously, the drill and fill method is novel in nature and as such no team compositions exist. Hypothetical normal and HATs were therefore created for the drill and fill method (Table 3.5). Compared to the felling method, it was assumed the drill and fill method was safer in terms of worker safety as trees are left standing thus requiring no supervision, which gave the assumption that there was no limit to the amount of drill operators which could be added to a team.

Table 3.5: Assumed Normal and High-Altitude Drill and Fill Team Compositions

Normal Team Composition	High Altitude Team Composition
1 x Contractor or Supervisor	1 x Contractor
11 x Drill and Fill Operators	11 x Drill and Fill Operators

Once these daily team rates were calculated, other costs included in determining a person day cost of clearing: UIF, capital build up, administration and transport were added.

The data was then organized into Excel spread sheets for normal and HATs (Annexure G). The purpose of these models was to eventually achieve a daily cost of each worker job type which could be applied to the person day or work rate matrixes to get an eventual total team cost based on a specific work rate combination.

Each of the above-described variables affecting work rates: Density class of infestation (D), Slope (S), Obstructive vegetation density (OVD), after being adapted for the study, were then incorporated into a 'work rate matrix'. The incorporation of the matrix allowed one to get the work rate amount or person days per hectare for an infestation based on a certain density, slope or OVD class combination as shown in the Figure 3.2 below (Annexure H). The 'access time factor' to the clearing site is not shown as this is a work rate factor accessing a site, and for purposes of the study this was kept separate from the other clearing site work rates shown below which purely relate to clearing costs on the site before site accessibility is considered.

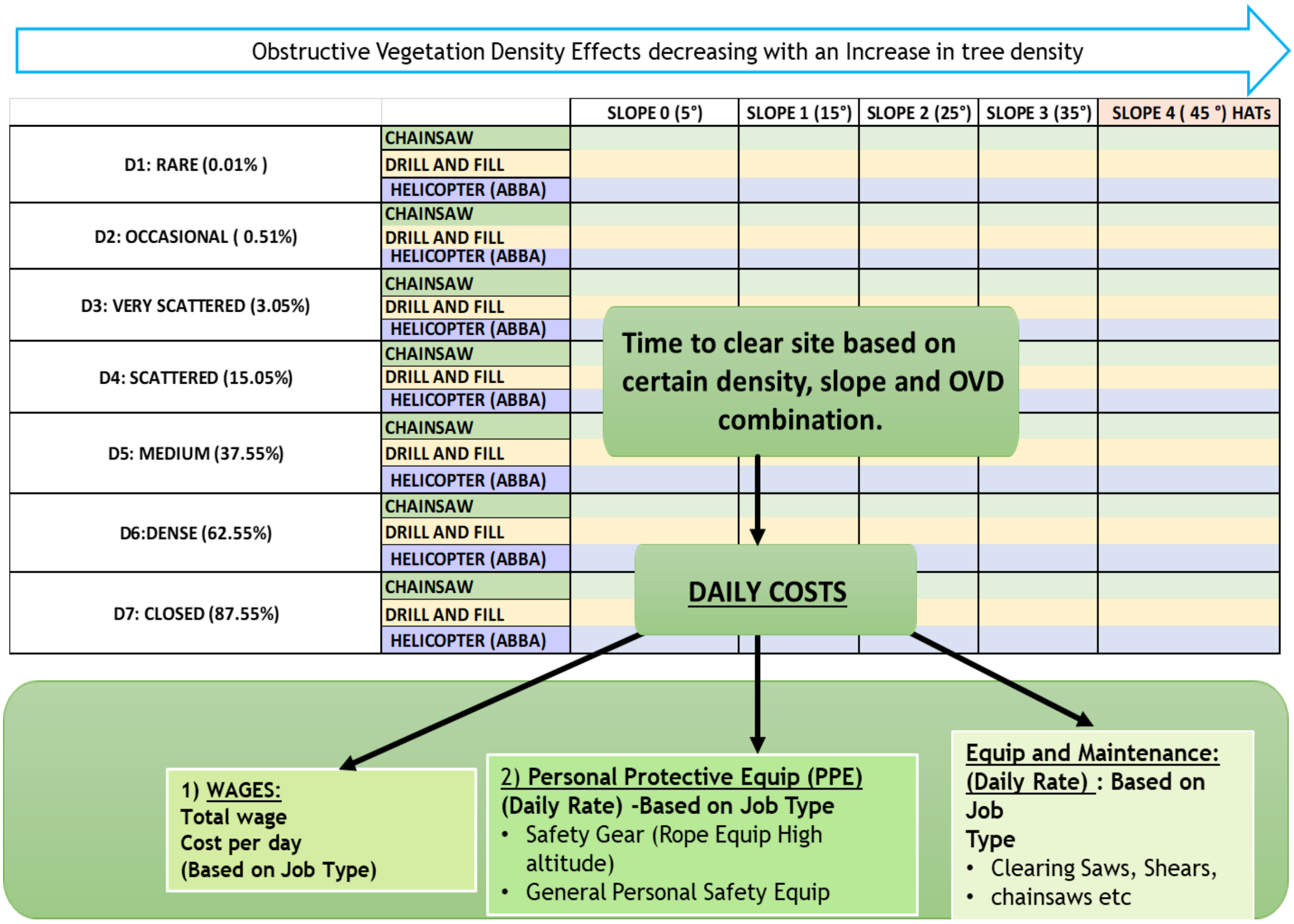

Figure 3.2: Schematic representation of the work rate matrix

After the total person days or work rate for a contract team were calculated in the model at each of these combinations, each combination was then multiplied by the specific clearing methods 'total daily team rate' to achieve a total costs per hectare of each method. Estimated total herbicide costs per hectare was also calculated if applicable, and transport costs also added in the model at specific R/km rates if access time is required for reaching the site.

3.5 Application of Model to Pine Ground Control Scenarios

3.5.1 Chainsaw Clearing Teams

3.5.1.1 Felling time

The total amount of felling time in person days per hectare can be estimated according to the number of trees present per hectare (Neethling & Shuttleworth, 2013:8). The work study showed it took one chainsaw operator 0.59 minutes to fell an adult tree (10-15cm DBH), which was based on a maximum available work time of 410 minutes in a standard 480-minute shift after non-productive allowances were considered. The study thus concluded one chainsaw operator could fell an equivalent 700 trees/ha in a standard 8-hour shift (Neethling & Shuttleworth, 2013:8). As discussed previously, using this information, one could get the amount of felling time in person days it would take one chainsaw operator to clear a condensed hectare at 100% cover based on the equivalent 12430 plants/ha in a condensed hectare. It was calculated it would take one chainsaw operator 17.76 person days to clear a condensed hectare at 100% cover. This value thus represented the chainsaws 'felling time' component, which was then scaled down according to each of the seven-midpoint cover class's equivalent condensed hectare values and slope class combinations respectively.

3.5.1.2 Costs

Wages

In order to calculate benchmark prices for clearing contracts, wages for each job type are set to a national minimum daily equivalent task wage rate and communicated in a circular each year (Mfusi & Govender, 2015:1 ; Sadan, 2005:16). The minimum daily equivalent task wage rate is calculated for each job type for both normal and HATs by adding the baseline daily equivalent rate and compensation for leave days (as shown in Annexure I) whereby compensation for leave days is calculated as 16% on the baseline daily equivalent rate.

Apart from the contractor, chainsaw operators receive higher wages due to the higher skills and training required compared to other clearing roles such as general workers (Sudan, 2005:16). The minimum daily equivalent task wage rates were used for determining the total normal and high-altitude daily wages. Based on personal communication SRAT managers (Leukes, personal communication, 2019) it was discovered that, compared to normal teams, rope access technicians (RAC) are all trained with the same skills and thus receive the same wage as a rope access technician regardless of role. This resulted in the following wages for the following job types as shown in Table 3.5 below:

Table 3.6: Daily Wage Rates for Normal and High-Altitude Chainsaw Teams

	Job Type	Daily Wage Rate
Normal Teams	Chainsaw Operator	R 146.35
	General Worker	R 116.70
High Altitude Teams (HATs)	Rope Access Technician (RAC)	R 187.11

PPE and Equipment

PPE and equipment for the normal chainsaw team compositions, as mentioned in previous sections, were obtained from national clearing data which provides the necessary PPE and equipment items needed per specific job type, along with their relevant quantities and lifetimes of each item (Annexure

F). The unit prices of these items were obtained from WfW operational spread sheets and inflated to current year prices in order to get a total daily rate per job role This resulted in the following PPE items and prices for a chainsaw operator and general worker as shown in Table 3.7 and Table 3.8 respectively (see Annexure G).

Table 3.7: Chainsaw Operator PPE and Equipment List and Prices

	Product	Price per Item
Personal Protective Equipment (PPE)	Blue Overalls (Jacket and Trousers)	R 144.17
	Safety Boots (Carbon/ Steel toe Cap)	R 374.71
	Chainsaw Helmet (EU Standard)	R 505.52
	Safety Pants (EU Standard 11 Layers)	R 1 012.81
	Chainsaw Gloves	R 262.65
	Webbing Belt	R 72.22
	Whistle	R 18.93
	Pressure Bandage	R 22.66
Equipment	Combi Can	R 399.80
	Fire Extinguisher	R 449.00
	Sharpening Kit	R 215.47
	Chainsaw	R 8 697.95

Table 3.8: General Worker PPE and Equipment List and Prices

	Product	Price per Item
Personal Protective Equipment (PPE)	Blue Overall (Jacket and Trousers)	R 144.17
	Safety Boots (Carbon/Steel Toe Cap)	R 374.71
	Hard Hat	R 29.48
	Leather Gloves (Wrist Length)	R 40.24
	Rubber Gloves (Short Length)	R 22.38
	Safety Goggles (Eye Protection)	R 42.87
	Raincoat (Jacket and Trousers)	R 109.69
	Gumboots (Steel Toe Cap)	R 216.66
Equipment	Equipment Harness	R 610.86
	Lopping Shears	R 1 203.96
	Pruning Saw	R 727.44
	Axe	R 136.91
	Spray Can	R 124.82

In practice for HATs, rope access technicians (RAC) would have the same PPE and equipment as a general worker in a normal team but with the additional specialized high angle equipment (De Smidt, personal communication, 2019). HAT rope access personnel therefore had the same PPE and equipment daily rates as the normal teams as shown above, but with additional rope access equipment daily rates added. The specialized rope access equipment daily rates were calculated based on prices and lifetimes obtained through cost guidelines and requirements for implementing specialized remote access teams (Leukes, 2020).

Chainsaw Mechanisation Costs

The cost of a machine is usually calculated on an hourly basis to get the machine rate, which is normally divided into the ownership, operating and labour costs, however in some cases when the labour operating the machines are working at different number of hours, then labor costs are alternatively excluded and calculated separately (FAO, 1992). In the study, labour hours differed and thus were calculated separately from machine costs.

Chainsaw machine costs were calculated in accordance with the methods by the European Cooperation in Science and Technology (COST) Action FP0902 for determining transparent machine rate cost calculation's based on standardized and current costing procedures in the forestry industry (Ackerman *et al.*, 2014:76). The model was developed to establish a common framework and transparent cost calculations in forest operations research. Using this framework and the rules of thumb for chainsaw cost calculations (Ackerman *et al.*, 2014:76-79) the costs were subdivided into their respective fixed, variable and operator costs and the following assumptions made:

- Cost of lubricant calculated as 20% on fuel cost.
- Residual value at 10% of purchase price
- Expected economic lifetime 1000 PMH
- Straight line method of depreciation
- Repair and maintenance at 100% on replacement value

Data on the chainsaws hourly fuel consumption, the model and consumables were obtained directly from WfW machine cost evaluations while the service life and maintenance costs of the chainsaw were taken from Calvo *et al* (2013:267-268). The model chainsaw and attachments were originally presented in 2015-year values and thus inflated to current year values. The fuel prices were derived from the South African Department of Energy (DOE, 2020). The interest rate was assumed at 12 percent which, as explained by Miyata (1980:6) can be used as a rule of thumb for calculating interest rates.

Operating or variable costs include the fuel, oil, maintenance and consumables which are incurred when the machine is running and change in proportion to the hours of operation, or when the machine is actually working which is usually based on a machines utilization rate (Ackerman *et al.*, 2014:78-79). These variable costs were applied at each midpoint density class by calculating their equivalent number of productive machine hours (PMH) at each midpoint cover's estimated equivalent number of plants/ha.

Ownership or fixed costs are costs which occur constantly and do not vary with the amount of hours the machine is in use and must be spread over the hours of work for the year, which is defined as the scheduled operating time (SMH) and can be described as the time during which equipment is scheduled to do productive work which is calculated by the estimated number of machine shifts per year multiplied by the amount of hours per shift (Akay, 1998:7; Bushman & Olsen, 1988:7). These costs include depreciation, interest, insurance, and taxes (Miyata, 1980:4). Depreciation and interest were calculated based on an SMH of 1488 per annum (8 hours a day x 186 working days).

3.5.2 Drill and Fill Clearing Teams

3.5.2.1 Drill Poisoning Time

New Zealand literature provides information on herbicide quantities and the amounts per tree for the drill and fill methodology, however based on the study area, *Reglone* (*Diquat*) was chosen as the preferred herbicide to be applied at an amount of 1ml per each 1cm drilled hole per tree, thus giving 2ml per tree based on two drilled holes per tree for a 24cm DBH tree. This was based on field trials undertaken in the Western Cape Fynbos by Donald (1982:3-4) on *P. pinaster* in the fynbos biome through chemical application in drilled holes. The investigation showed best mortality rates were experienced by injecting 1ml of Reglone into the sapwood of each 9.5mm drilled hole at two holes per tree which was effective up to a DBH of 24cm.

Team compositions using this method have involved operators working in pairs with one person drilling the trees while the other administers the herbicide and marking the treated trees (Kingdom, 2009:366). The study by Donald (1982:5) has however argued that in practice this method can result in some trees being drilled and left untreated. It was thus assumed each drill operator would both drill and apply the herbicide to each tree.

To estimate the drill and fill treatment times per tree a field trial was undertaken on a dense *P. pinaster* plantation in Jonkershoek in Stellenbosch. A total of 20 trees were randomly chosen and treated within the selected 24cm DBH range for the study. The average DBH of the stand was 11,4cm and trunk holes were located 1m above the soil surface. A Makita DHP481 cordless drill with a 5Ah fully charged battery was used to drill two 9.5mm deep holes into each tree at an angle of 45 degrees. Due to lack of permits for allowing the dosage of the chosen herbicide for the study area water was used in its place and injected into each tree using a plastic syringe. Comparisons were also made between different drill bit types and high and low gear output settings of the drill in order to measure the differences in their overall ability to save power and provide faster drilling times.

A 11mm wood bit was firstly tested and it was noted at this size the holes were unnecessarily large to hold the herbicide in place which would compromise on battery and drilling times. It was thus decided to use an 8mm fast drilling steel bit in low gear which would save on overall battery power and drilling times (September, personal communication, 2019). At the 5Ah battery capacity a total 250 holes were drilled before the battery was exhausted. The average time to drill one hole took four seconds and it was decided to use seven seconds per hole to be more conservative in the estimations. Based on the literature it is advised the herbicide must be filled within a time frame of 10-15 seconds after each drilled hole is filled (Dufour-Dror, 2013:13) and thus 10 seconds was added to each drilled hole which equated to a total of 20 seconds to each tree to account for the time from drilling a hole to the start of herbicide application. The time to fill each hole with herbicide solution equated to an average time of eight seconds.

Accounting for all these individual time components and based on an assumed two holes per tree, a total average application time 0f 0.83 minutes (50 seconds) per tree was given. Based on the maximum available work time of 410 minutes after non-productive allowances from a standard 480-minute (8 hour) shift, resulted in a total of 492 trees/ha that could be treated by one drill operator, to clear a condensed hectare. Based on the assumed 12430 plants/ha at 100% cover gave a value of 25.26 person days for one drill and fill operator to clear a condensed hectare.

3.5.2.2 Costs

Wages

As mentioned in previous sections, chainsaw operators receive higher wages compared to other clearing roles such as general workers as they must possess higher skills and training (Sadan, 2005:16). The drill and fill method can be assumed to be a much safer alternative compared to chainsaw operation and as such it was assumed a drill operator would have similar skills and training as a general worker. Based on the aforementioned information, a drill and fill operator was given the same minimum daily equivalent task wage rate for a general worker in a normal chainsaw team. The same principle was assumed for the high-altitude drill and fill operators, whereby the daily wage was assumed the same as a rope access technician (RAC) in a high-altitude chainsaw clearing team (See Table 3.6).

PPE and Equipment

PPE and equipment for undertaking the drilling was obtained from New Zealand drill and fill best practice guidelines, as shown in Annexure B. Drilling equipment options consisted of either using petrol powered or lithium-ion model drills. As explained in the previous section, for the studies purpose, the lithium-ion drill option was chosen.

Drill operators PPE items (shown graphically in Figure 2.1) were the same to that of a general worker in the normal chainsaw clearing teams, which was also confirmed from the New Zealand best practice guidelines. As shown in Figure 2.1, gloves must be of elbow length to accommodate herbicide applications, which were similar to that found in a normal WfW herbicide applicators PPE (Annexure F). A Drill and fill operators PPE items were of general nature and thus the same daily rates used for the normal chainsaw clearing teams were used for these items (Annexure G), which resulted in the following PPE items as shown in Table 3.9 below.

Table 3.9: Drill and fill Operator PPE and Equipment List and Prices

	Product	Price per Item
Personal Protective Equipment (PPE)	Blue Overall (Jacket and Trousers)	R 144.17
	Safety Boots (Carbon/ Steel Toe Cap)	R 374.71
	Hard Hat	R 29.48
	Safety Goggles (Eye Protection)	R 42.87
	Rubber Gloves (Elbow Length)	R 43.90
Equipment	Makita Drill	R 5 600.00
	18V Li-Ion 5.0Ah Rechargeable Battery	R 1 480.00
	20ml Drencher and 2.5 Litre Dosing Backpack	R 2757.00
	Drill Bits 12mm Steel Auger	R 250.00
	Equipment Harness	R 124.82
	Pruning Saw	R 727.44
	Fire Extinguisher	R 449.00

As explained in drill and fill best practice guidelines, operators can either dispense the herbicide via squeeze bottles or backpack applicators. The backpack method of application was chosen because it would allow operators more mobility out in the field, more precise herbicide dosages per tree and less refilling times (Boyd, 1985:26). Other equipment items according to the best practice guidelines included the fire extinguisher where the daily rate for this item was obtained from the national AIP operational data (Annexure G).

The backpack applicator option included a 20ml drencher gun attached to a 2.5 litre dosing backpack container. Quotations and lifetimes relating to the drill itself, its batteries and drill bits were obtained locally from the manufacturer (September, personal communication, 2019). The drencher gun and backpack container prices and lifetimes were obtained from a local veterinary supplier in the region and consolidated in Table 3.9 (Annexure J).

As mentioned in Chapter 2, compared to the petrol-powered alternative the electric drill needs to be recharged, which can place limitations on how many trees can be treated while out in the field (Badalamenti & La Mantia 2013:124-125). It was therefore assumed drill operators would carry a total of four batteries during each shift to prevent the need to recharge. The number of batteries was based on the assumed 125 trees that can be treated with each fully charged 5Ah battery and the estimated 492 trees that can be poisoned per shift, which gave a total of four 5Ah batteries needed per operator to prevent recharging (492 trees per shift/ 125 trees per battery = 3.94 batteries per operator/shift). It was additionally decided, for purposes of the study area, to include a pruning saw per operator for the movement of obstructive vegetation while on site. The daily rate of the pruning saw was obtained from the national AIP operational data (Annexure G).

Herbicide Costs

In terms of non-target effects, *Reglone* as mentioned by Donald (1982:5-6) has minimal non target effects on the environment from its absorption into the cellulose of the tree after its eventual death. Studies also undertaken by Ray & Davenhill (1991:21) which tested twelve different herbicides on self-sown *Pinus contorta* of varying age, size and heights in New Zealand also showed *Reglone* (*Diquat*) had the highest mortality rates with the least non- target effects. Based on these studies, in terms of mortality rates and minimal non- target effects, it was decided that *Reglone* would be chosen as the desired chemical to be applied at the chosen 2ml per tree. *Reglone* prices were based on quotations obtained from a local herbicide company as shown in Annexure K. Based on the amount of herbicide per tree, the cost of herbicide per hectare at each of the respective seven midpoint density classes was calculated based on the corresponding number of plants/ha adapted from the WfW mapping standards (Le Maitre and Versfeld, 1994:6).

3.6 Application of Model to the Aerial Basal Bark Application (ABBA) Method

3.6.1 ABBA Poisoning Time

The treatment component was calculated using the same methods applied to both the chainsaw and drill and fill ground-based control methods, whereby the total treatment time per tree was used as the starting point, which in this case was the total spray time per tree using the ABBA method for the species. This spray time was calculated based on previous studies that concluded that the most effective ABBA treatments at the different height classes used 1000ml of herbicide (Gous *et al*., 2015:380; Gous *et al*., 2014:1). Operational guidelines outlining ABBA wand specifications guidelines (Eschenmoser, 2013:7) recommend a nozzle pressure of four bar for preventing unnecessary spray drift and damage to the nozzle body, which as stated has resulted in a total herbicide output of 200ml a second. Using equation 3.7 below, this gave a total treatment time of five seconds per tree using the ABBA method.

Equation 3.7: ABBA Poisoning time per tree

$$1000ml\ required \big/ 200ml\ per\ second$$

Based on the assumed maximum available work time of 410 minutes after non-productive allowances from a standard 480-minute (eight hour) shift this gave a total of 4920 trees/ha that could be treated with the ABBA method to clear a condensed hectare. Based on the assumed 12430 plants/ha at 100% cover gave a value of 17.26 hours for the ABBA method to clear a condensed hectare. Compared to the ground-based clearing methods, it was decided for the ABBA method to work with an hourly figure instead of a ‘person day’ rate as the helicopter is charged on an hourly basis (Howat, personal communication, 2020). This value could then be scaled down according to each midpoint cover class's equivalent condensed hectare value to represent the ABBA methods 'treatment time' component.

3.6.2 Costs

3.6.2.1 Introduction

It was decided that to recognise which cost factors drive differences between the chosen ground methods and the ABBA method, a breakdown of the various cost components would be needed for the ABBA method, and it was decided to follow the transparent accounting framework as developed by Wenger *et al* (2014:1300) on how to accurately calculate the helicopter clearing costs for invasive species management. This accounting framework developed for aerial AIS control costs involving helicopters, includes both the travelling and treatment components which were subdivided into four major cost components as shown below:

- Travel (T)
- Labour (L)
- Consumables (C)
- Equipment (E)

As explained by Wenger *et al*, (2014:1292), these four broad cost components can be further broken down into parameters that would usually be found on itemized budgets, while actual costs are based on actual quotes received from contractors and companies selling the consumables. This accounting framework was also mentioned as being able to be readily adaptable to other management actions with similar components (Wenger *et al*., 2014:1300).

It was thus decided to use the same accounting framework and cost components, however for purposes of the study it was decided to add a fifth cost component termed 'overheads' which would make the ABBA method more comparable to the ground methods where an overall overhead cost of 32.5% was added onto direct clearing costs as shown in previous sections.

The same steps as outlined in the framework above were thus followed and adapted for the study whereby each cost component was quoted based on close consultation with a local helicopter company willing to undertake such an operation in the study area with the required practical experience and knowledge available. Each component applied to the ABBA method will now be discussed.

Table 3.10: Source of cost information for budget items

Budget Item	Source
Helicopter ferry and site direct operating costs, personnel wages, overheads, and ground support vehicle	Helicopter company in the region that has been previously contracted to conduct ABBA trials for the Western Cape.
Personnel PPE and equipment items	ABBA operational guidelines. Quantities, prices and lifetimes from local national AIP clearing data.
Monitoring Equipment	ABBA best practice guidelines. Quantities, prices and lifetimes from developers.
Herbicide Spray Wand Equipment	ABBA best practice guidelines. Quantities, prices, and lifetimes from practitioners in other countries who created and currently pioneering the method.
Consumables	ABBA best practice guidelines. Chemical costs from local chemical supply companies in the region.

3.6.2.2 Travel Costs

Due to the overall terrain and high-altitude work that can take place in the study area, and the advantages the MD500 has in being able to work in these areas, the MD500 was chosen as the machine to be used in the study as shown in Chapter 2. As highlighted in Table 2.2, although relatively more expensive in purchase price, the MD500 is the preferred aircraft in terms of safety and efficiency due to its dimensions and hovering capabilities in rough terrain. Travel costs as defined for the study, were the direct operating costs experienced by the helicopter while ferrying to the clearing site, conducting the actual spray operation over the clearing site itself, and the transport of the ground support vehicle to the nearest road of the clearing site.

Helicopter ferrying was recognised as involving two components: the ferrying from the hangar or base of operations and the ferrying to the ground support vehicle, whereby the latter component would be situated to the nearest road for refuelling of either the helicopter or herbicide tanks if required. It must be noted that the assumed walking distance of 3km from the nearest road to the Nbal for the ground teams was not accounted for in the calculation of ferrying costs as at this distance and with the speed (80 knots) of the aircraft its effects would be negligible (Howat, personal communication, 2020). For the study's purpose it was decided to only include ferry distances of ≤ 30km and exclude any additional ferrying distances over this amount. This distance, as explained in previous sections, was within the assumed average drive distance of 30,28km for ground teams from the project office to the nearest road of the clearing site. Ferrying costs from the hangar to the clearing site, as explained by the helicopter company (Howat, personal communication, 2020) would already be accounted for in the quoted hourly direct operating costs of the aircraft for ferry distances of ≤ 30 Km which was quoted at R14 156 per hour, while ferrying distances above this would be charged at an additional R16 172 per hour. It must also be noted that the quoted hourly clearing cost of R14 156 also included the transport of the ground support vehicle to the nearest road of the clearing site (Howat, personal communication, 2020).

3.6.2.3 Labour

The labour component consisted of the wages, PPE, and equipment according to each job type and applied to the following team composition as shown in Table 3.11. As explained in Table 3.10, wages were quoted from a private helicopter company. The pilot's wages were however quoted at higher rates compared to normal standards due to the higher level of experience and risks involved in such an operation (Howat, personal communication, 2020).

Table 3.11: ABBA team composition

1 x Pilot
1 x Ground Operator
1 x Wand Operator

Source: Raal (2014).

Table 3.12: ABBA wage rates per job type

Job Type	Annual Wage
Experienced Agricultural Pilot	R 720 000
Herbicide Wand Operator	R 420 000
Ground Support Operator	R 120 000

PPE and equipment list per job type were obtained from New Zealand ABBA operational guidelines (Raal, 2014:19-28). Where ABBA PPE and equipment items per job type were recognised as being of a general nature, the prices, quantities and lifetimes of such items were obtained through the local AIP clearing data as previously shown in Annexure G. Unique PPE and equipment items prices, lifetimes and quantities per job type were obtained through personal communication with the chosen helicopter company and the accuracy of the general items prices, quantities and lifetimes were also confirmed (Howat, personal communication, 2020). It must be noted that there were no equipment items present for the pilot and wand operator, however, as outlined in the operational guidelines, an emergency response kit containing a first aid box, fire extinguisher and radio locator beacon must be carried by the wand operator during each operation (Rail, 2014:28) and as such these were added to the wand operator's equipment list to account for these items (Table 3.14).

Table 3.13: Pilot PPE and Equipment List and Prices

	Product	Price per Item
Personal Protective Equipment (PPE)	Blue Overall (Jacket and Trousers)	R 144.17
	Safety Boots (Carbon/ Steel Toe Cap)	R 374.71
	Safety Goggles (Eye Protection)	R42.87

Table 3.14: Wand operator PPE and Equipment List and Prices

	Product	Price per Item
Personal Protective Equipment (PPE)	Blue Overalls	R 144.17
	Safety Boots (Carbon/ Steel toe Cap)	R 374.71
	Safety Goggles (Eye Protection)	R 42.87
	Rubber Gloves (Elbow Length)	R43.90
	Ear plugs (pair)	R 13.31
Equipment	First Aid box	R 649.95
	Fire Extinguisher	R 449.00
	Radio Locator Beacon (PLB)	R7176.00

Table 3.15: Ground Operator's PPE and Equipment List and Prices

	Product	Price per Item
Personal Protective Equipment (PPE)	Blue Overall (Jacket and Trousers)	R 144.17
	Safety Boots (Carbon/ Steel Toe Cap)	R 374.71
	Hard Hat	R 29.48
	Rubber Gloves (Elbow Length)	R 43.90
	Safety Goggles (Eye Protection)	R 42.87
	Capes (Head, Shoulders and Back)	R 116.18
	Masks (48/year= 4/ Month)	R 17.40
	Leggings	R 196.29
Equipment	Jugs and Buckets	R 119.10
	Plastic Container 25 litre	R 87.38
	Utility Pliers	R 201.43
	Handheld Radio	R 5 500.00
	Weather Station	R 5 000.00

3.6.2.4 Equipment

As explained in previous chapters, based on ABBA good practice guidelines (Biosecurity New Zealand, 2020b:8-9), specialized spray equipment would need to be fitted (Table 3.16). A ground support vehicle would also be required for the refilling of herbicide during operations. Prices and lifetimes for the monitoring equipment: VAL2 was quoted from the developers (Howell, personal communication, 2020). As explained in Chapter 2, VAL2 provides operations with the following important added abilities for monitoring, such as documenting: herbicide volumes, the species locations and search paths taken during operations.

In terms of the spray wand equipment, as shown in Table 3.16, it was advised that it in terms of the twin staged centrifugal pump used for dispensing the herbicide, it was advised to use a small reciprocating herbicide agricultural pump, while additionally the price, model and assumed lifetime was provided (Howat, Personal Communication, 2019). Prices for the item were obtained online at market price. The lifetimes, quantities and prices of the herbicide spray wand equipment were obtained via communication with necessary practitioners currently pioneering the method who have the most experience at present (Raal, personal communication, 2019).

Table 3.16: ABBA Specialized Equipment List and Prices

	ABBA Equipment	
	Product	**Price Per Item**
Monitoring Equipment	Volume and Location Tool (VAL2)	R 6 712.44
Spray Wand Equipment	Small Reciprocating Agricultural Pump	R 7 795.00
	Herbicide Spray Wand	R 11 187.40
Ground Support Equipment	Ground Support Vehicle	R 380 000.00

As shown in Table 3.16 above, other additional equipment items included a ground support vehicle for the refilling of the aircraft. After consultation with the literature, it was difficult to construct an overall cost for this item, as this equipment item would also have to be fully equipped with further additional items. It was thus decided to obtain the hourly cost of this item from the chosen private helicopter company (Howat, personal communication, 2020).

3.6.2.5 Overheads

As mentioned previously, overhead costs of 32.5% were included on the direct clearing costs of the ground-based methods, and as such it was decided that, in order to make the ABBA method more comparable to that of the ground-based methods, overheads would need to be included. Based on communication with the local helicopter company (Howat, personal communication, 2020), the following annual overhead costs were included in the ABBA methods total hourly rate.

Table 3.17: ABBA Overheads

Overheads	
Item	**Annual Overheads**
Hangar Rental	R340 800
Insurance	R420 000
Licences	R100 000

3.6.2.6 Consumables

The total herbicide costs (Rands) per hectare density (Ha) class was calculated as:

$$Hc = AtHtDs$$

The herbicide cost per hectare density class (Hc) depends on the herbicide application rate per tree in litres (Ht), the cost of the chemical per litre (At) and the number of stems per hectare at each midpoint cover class (Ds). The assumed one litre of herbicide per individual tree as mentioned previously was taken as a starting point and the total herbicide costs per individual tree was calculated by obtaining the cost of the chemical per application unit (At) at the market price. For this research triclopyr was chosen as the desired herbicide which was based on New Zealand ABBA best practice guidelines (Biosecurity New Zealand, 2020b:8). It must however be noted that during the study due to the novelty of the method in South Africa, triclopyr is not a registered herbicide for use in the study area and additional studies still need to take place regarding choice of herbicide and thus the quoted concentrations in this study was merely used to provide the closest possible realistic estimation in terms of herbicide cost per tree with the highest mortality rates (Annexure L).

3.6.2.7 Cross Subsidisation

The number of actual flight hours available per year was also discovered to be an important consideration when calculating an accurate cost for the ABBA method. As previously mentioned, the study consulted a private contractor which would allow a higher level of hours available per annum. The was because the private contractor used in the study was also involved in crop spraying in agricultural areas. Alien invader tree eradication using the ABBA method as explained in Chapter 2 usually involves spraying individual trees in remote and inaccessible locations. These mountainous areas as shown in practice in the study area, can at times be windy and thus dangerous to work in, which place limitations on the number of hours that can be dedicated to alien tree eradication (Howat, personal communication, 2020). Under these conditions the use of a private contractor also involved in agricultural crop spraying thus gives one a significant advantage in terms of cost saving. This is because alien invader tree eradication can be diverted to crop spaying in lower lying and safer locations when the weather is not permissible and can then resumed when the weather becomes more favourable which allows these agricultural activities to 'cross subsidise' and lower the potential costs of the ABBA method. These advantages of this cross subsidisation would thus make a privately contracted helicopter company more financially beneficial compared to a government owned helicopter obtained solely for invader tree eradication standing idle at certain periods of the year.

3.7 Conclusion

The purpose of Chapter 3 was to present and explain the development of the work rate model, which is important as it provides the reader with the relevant information as to how the values in the model were calculated and how the various elements composed in the work rate model are connected. The adaption of the work rate variables was outlined. The challenge was to adjust these work rate variables to the conditions of the study area and translate this work rate data into financial data at the various combinations. A work rate matrix was constructed to capture these differences at the various site combinations whereby each component was explained in detail.

The model was designed to be robust and dynamic for the field manager in practice so various site conditions, control method and team compositions could be inputted and transformed into financial data to be compared between the different control methods.

Alien invasive pine clearing experts and AIP costing data was identified and how these contributions were used in the model were also discussed. Although more work rate and costing data existed for the chainsaw ground teams, the novelty of the drill and fill and ABBA method was mentioned and as such close consultation had to be undertaken to develop some of these work rate and costing data.

The Excel model contained multiple components that were interrelated with one another and changes in cone component made by the user would affect or influence the changes throughout.

Chapter 4: Application of Model and Results

4.1 Introduction

The main purpose of the study was to compare the costs per hectare of the traditional chainsaw clearing method with two novel clearing methods: the 'drill and fill' and 'ABBA' methods. To accomplish this typical team compositions were constructed through operational literature and discussions with field experts with the needed knowledge which assured the assumed team compositions were representative of the typical compositions found in practice in the Western Cape. The development of the 'work rate matrix' was discussed in Chapter 3. The calculation elements were also explained in detail as to allow the reader to understand how the various physical site characteristics, namely tree density, obstructive vegetation density, site access and slope can be incorporated into different combinations in the model. The model construction was discussed in Chapter 3 is used to calculate the costs per hectare of the three clearing methods to compare which method would be cheaper at these various clearing site combinations.

The second section is devoted to the analysis of the results of the three clearing methods that have been modelled. This section discusses key trends and components found in the various combinations between the different clearing methods. The physical site characteristics of each combination were assumed to be the same at each specific combination to make them comparable. The chainsaw clearing method consisted of a standard chainsaw operator as found in a standard WfW normal chainsaw clearing team. The drill and fill clearing alternative consisted of an assumed drill and fill team fully committed to the drilling and filling of trees which consisted of 11 drill and fill operators in a team. The ABBA method consisted of a team composition based on communication with practitioners operating on a relatively small scale in the region, as well as in New Zealand where the method is being applied on a larger scale.

This chapter is divided into three sections. The first section explains the structure of how the results are presented and the scenarios introduced in each dataset. The last two sections present the results of the different clearing strategies.

4.2 Model and Scenario Description

In addition to the standard clearing strategies and compositions as described in Section 4.1, it was decided to include an additional scenario to compare the results of a typical chainsaw clearing team in response to additional chainsaw operators with the typical drill and fill team both adjusted to their maximum productive worker rate. In addition, in relation to the ABBA method, it was decided to include two additional scenarios which tested the addition of the 'accessibility' (walk and drive time) component. All scenarios were tested as to determine if a method would become more cost efficient at a specific combination. As a result, three scenarios were modelled as follows:

4.2.1 Scenario 1: Additional Chainsaw Operators

As discussed in Chapter 3, additional chainsaw operators added to a clearing team can yield improvements in productivity as more trees can be felled during a standard working shift. This scenario incorporated three additional chainsaw operators to a standard chainsaw team, which gave a total of four chainsaw operators in a team. A total of four chainsaw operators were chosen due to the risks in terms of worker safety from felling. Each chainsaw operator requires at least two general workers for safety and supervision within a total maximum allowable number of thirteen productive workers in a team. This composition was based and validated through discussions with experts in alien pine clearing in the region (Leukes, personal communication, 2019). With the drill and fill technique trees are 'killed standing' with a significant lower risk so that one could assume that a whole team could consist of drill and fill operators.

4.2.2 Scenario 2.1: Accessibility: 30km drive distance and 60-minute walk time

As discussed in Chapter 2, accessibility (walk time and drive time) to a site for ground teams can add to extended work times on a site as time is lost in reaching the site with the addition of transport costs. The helicopter, from its ability in accessing a site significantly faster in inaccessible areas compared to ground teams could result in cheaper costs per hectare. Access factors are quoted as one way in all scenarios, although return trips are taken into consideration in calculations, i.e., the one way walk time of 60 minutes to the site includes the return leg trip which thus amounts to a total walk time of 120 minutes. Drive time, as explained in Chapter 3 gave a total one-hour drive time in the model with the return leg trip considered and a drive distance of 30km. Drive distance was assumed from the project office to the road nearest to the Nbal while the remaining distance from the nearest road to the Nbal is considered as walking distance.

4.2.3 Scenario 2.2: Accessibility: A 60-minute walk time added to Scenario 2.1

The drive distance is assumed as in Scenario 2.1; however, an additional one way walk time of 60 minutes is added thus giving a total one way walk time of 120 minutes from the nearest road to the centre of the Nbal which thus amounted to a total walk time of 240 minutes. The scenario was added to facilitate the same comparisons between the ground teams and the helicopter/ABBA method as in Scenario 2.

4.3 Results comparing a typical Chainsaw and Drill and Fill Team

In Chapter 3, the physical combinations influencing the time to clear, the costs and the assumed team compositions were discussed in depth. The work rate matrixes calculate the costs per hectare for an infestation based on a site's tree density, slope, OVD class and team composition. The effects of the accessibility are not shown as it was kept separate from the other clearing site work rates, which purely relate on site clearing costs before accessibility is considered, as explained in Section 4.2.

Table 4.1: Team compositions for a typical chainsaw and drill and fill team

Chainsaw	**Drill and Fill**		**ABBA**
Normal	High Altitude	Normal	High Altitude
1 x Contractor	1 x Contractor	1 x Contractor	1 x Contractor
6 x General Workers	8 x Rope Access Technicians	11 x Drill and Fill Operators	11 x Drill and Fill Rope Access Technicians
1 x Chainsaw Operator	1 x Chainsaw Operator		
1 x H&S Worker	1 x H&S Worker		
1 x First Aider	1 x First Aider		
2 x Peer Educator			

The benefit of the drill and fill strategy at the assumed team compositions, as shown in Table 4.2, can clearly be seen across all combinations.

Table 4.3 shows that compared to chainsaw operators, drill operators have almost the same equipment daily rate from the specialized drill equipment: drill, drill batteries and herbicide equipment while, from the reduced skills and added safety from drilling compared to felling, a drill operator's wage and PPE daily rates are equivalent to that of a general worker. The high amount of drill operators in both their normal HATs results in the strategy having a higher total equipment daily rate compared to that of a standard chainsaw team thus resulting in a higher total daily team rate for the drill and fill strategy.

Table 4.4 shows that, when compared to the chainsaw strategy the drill strategy incurs a lower walk time cost per hectare due to the significantly lighter weight of the drill equipment compared to that of the chainsaw. The drill and fill method however incurs a higher herbicide cost per hectare at all density and OVD class combinations as depicted in column six on the right compared to the chainsaw's lower variable costs (fuel, oil, maintenance, and cutter spares) realized per tree respectively. In Table 4.4, the chainsaw strategy has a higher felling time cost per hectare compared to the drill strategy due to the higher productivity from the added drill operators at all density and OVD class combinations as depicted in the second left column.

Table 4.2: Costs per hectare at each site combination based on tree density, slope and OVD work rate combination

HELICOPTER	
CHAINSAW	
DRILL AND FILL	

		SLOPE 0 (5°)	SLOPE 1 (15°)	SLOPE 2 (25°)	SLOPE 3 (35°)	SLOPE 4 (45 °) HATs
D1: RARE (0.01%)	Slight (OVD1)	**R 67**	**R 70**	**R 74**	**R 82**	**R 144**
	Moderate (OVD2)	**R 94**	**R 97**	**R 103**	**R 114**	**R 200**
	Dense (OVD3)	**R 133**	**R 137**	**R 146**	**R 162**	**R 284**
D2: OCCASIONAL (0.51%)	Slight (OVD1)	**R 126**	**R 130**	**R 138**	**R 153**	**R 262**
	Moderate (OVD2)	**R 152**	**R 156**	**R 167**	**R 185**	**R 318**
	Dense (OVD3)	**R 191**	**R 197**	**R 210**	**R 232**	**R 401**
D3: VERY SCATTERED (3.05%)	Slight (OVD1)	**R 429**	**R 443**	**R 472**	**R 522**	**R 878**
	Moderate (OVD2)	**R 455**	**R 469**	**R 500**	**R 553**	**R 932**
	Dense (OVD3)	**R 493**	**R 508**	**R 542**	**R 599**	**R 1 013**
D4: SCATTERED (15.05%)	Slight (OVD1)	**R 1 928**	**R 1 988**	**R 2 119**	**R 2 344**	**R 3 875**
	Moderate (OVD2)	**R 1 950**	**R 2 011**	**R 2 144**	**R 2 372**	**R 3 922**
	Dense (OVD3)	**R 1 984**	**R 2 046**	**R 2 180**	**R 2 412**	**R 3 994**
D5: MEDIUM (37.55%)	Slight (OVD1)	**R 5 035**	**R 5 192**	**R 5 534**	**R 6 123**	**R 9 914**
	Moderate (OVD2)	**R 5 051**	**R 5 209**	**R 5 552**	**R 6 143**	**R 9 949**
	Dense (OVD3)	**R 5 076**	**R 5 235**	**R 5 579**	**R 6 173**	**R 10 001**
D6:DENSE (62.55%)	Slight (OVD1)	**R 8 931**	**R 9 211**	**R 9 817**	**R 10 861**	**R 17 245**
	Moderate (OVD2)	**R 8 941**	**R 9 221**	**R 9 827**	**R 10 873**	**R 17 266**
	Dense (OVD3)	**R 8 955**	**R 9 236**	**R 9 844**	**R 10 891**	**R 17 298**
D7: CLOSED (87.55%)	Slight (OVD1)	**R 13 321**	**R 13 738**	**R 14 642**	**R 16 200**	**R 25 280**
	Moderate (OVD2)	**R 13 324**	**R 13 741**	**R 14 645**	**R 16 204**	**R 25 287**
	Dense (OVD3)	**R 13 329**	**R 13 746**	**R 14 651**	**R 16 209**	**R 25 297**

.

Table 4.3: Normal chainsaw and drill operator wages, PPE and equip daily rates

Job Type	Wages (Rands)	Personal Protective Equipment (PPE) (Rands)	Tools and Equipment (Rands)
Chainsaw Operator	146,35	20,46	83.35
Drill/ Fill Operator	116,70	5,65	109.53

Table 4.4: Summary of cost differences of original model outputs

Density Class	Additional Felling time costs (R/ha)	Slight (OVD1) (R/ha)	Moderate (OVD2) (R/ha)	Dense (OVD3) (R/ha)	Additional Drill and Fill Herbicide Costs (R/ha)
D1	6.42	-2.35	3.04	26.94	0
D2	240.98	-2.34	3.03	26.81	2
D3	1448.71	-2.28	2.95	26.12	9
D4	7143.42	-1.99	2.58	22.89	58
D5	17827.70	-1.47	1.90	16.83	200
D6	29672.36	-0.88	1.14	10.10	438
D7	41565.07	-0.29	0.38	3.35	759

Firstly, the significance of the effect of the walking time component and the effect of OVD at density classes is highlighted. Table 4.4 shows that, compared to a conventional chainsaw team, the drill and fill strategy affords a lower walk time cost/ha at tree densities D1-D7 at OVD2 and OVD3 classes respectively compared to the chainsaw felling costs/ha.

An eleven drill and fill operator team shows a significantly higher productivity (5412 plants per shift) compared to a conventional chainsaw team (695 plants per shift). Table 4.4 shows that at density classes D1-D7, the optimized productivity of the added drill operators is highlighted. Table 4.4 shows that the expected effect of an increase in density class, results in a lower absolute change in herbicide and walk time cost per hectare for the drill and fill strategy as opposed to higher absolute change in felling time costs/ha realized by the chainsaw strategy. This shows the drill and fill strategy is less susceptible to a rise in density and OVD from the optimized productivity and lighter equipment respectively despite the higher herbicide costs realized per hectare density class.

4.4 Scenario 1: Modelling Outcome with Additional Chainsaw Operators

Scenario 1 is an alteration of the original model, which consisted of a typical chainsaw and drill and fill clearing team involving one chainsaw and eleven drill operators respectively. As discussed in previous sections, adding additional chainsaw operators to a typical chainsaw clearing team can yield increased productivity, which could result in a chainsaw clearing team being more beneficial at certain site combinations compared to the drill and fill method. The amount of chainsaw operators allocated to the typical alien invasive chainsaw clearing team was increased by an additional three chainsaw operators, which gave a total of four chainsaw operators in a team. As explained previously, in terms of worker safety from felling, each chainsaw operator requires at least two workers, either a general worker, first aider or health and safety worker job type for supervision within a maximum of 13 productive workers in a team. In order to keep the same amount of productive team members throughout both methods, two additional drill and fill operators were added to both their original normal and high-altitude teams. The model makes it easy for one to change a team composition utilized for each method.

In the team composition sheet, the changes are entered into the individual chainsaw and drill and fill team composition tables. The number of general workers and rope access technicians allocated to the normal and high-altitude chainsaw teams are both reduced by one respectively, while the amount of chainsaw operators in both teams are increased by three. In the drill and fill team compositions the amount of drill and fill operators are increased by two in both their normal and high-altitude teams.

These changes in team compositions are linked to all the information in the assumptions sheet, which includes the total daily rates (PPE, wages, tools) of each job type used for calculating a team's total daily rate based on a chosen team composition. The inputted number of chainsaw or drill and fill operators is also linked to the number of plants that can be treated per shift for each method in the assumptions sheet in the 'Nbal Time Calculations' sheet. These few alterations to the original model allow the decision maker to simulate a different team composition in an easy way. The changes made will influence the total costs/ha between both ground methods at the various combinations.

Table 4.5 shows the team compositions of both methods that were used for Scenario 1, while the ABBA method is not shown, as this remained unchanged. The changes in chainsaw team compositions were validated by communication with specialized high altitude clearing managers with the needed practical knowledge and changes to the drill and fill teams were assumed to have no limitations from the methods added safety compared to felling.

Table 4.5: Team compositions for clearing scenario 1.

Chainsaw		**Drill and Fill**	
Normal	**High Altitude**	**Normal**	**High Altitude**
1 x Contractor	1 x Contractor	1 x Contractor	1 x Contractor
5 x General Workers	7 x Rope Access Technicians	13 x Drill and Fill Operators	13 x Drill and Fill Rope Access Technicians
4 x Chainsaw Operators	4 x Chainsaw Operators		
1 x H&S Worker	1 x H&S Worker		
1 x First Aider	1 x First Aider		
2 x Peer Educator			

Table 4.6: Costs per hectare at each site combination based on tree density, slope and OVD work rate combination

HELICOPTER	
CHAINSAW	
DRILL AND FILL	

		SLOPE 0 (5°)	SLOPE 1 (15°)	SLOPE 2 (25°)	SLOPE 3 (35°)	SLOPE 4 (45 °) HATs
D1: RARE (0.01%)	Slight (OVD1)	**R 77**	**R 80**	**R 85**	**R 94**	**R 166**
	Moderate (OVD2)	**R 108**	**R 111**	**R 118**	**R 131**	**R 231**
	Dense (OVD3)	**R 153**	**R 158**	**R 168**	**R 186**	**R 328**
D2: OCCASIONAL (0.51%)	Slight (OVD1)	**R 134**	**R 139**	**R 148**	**R 163**	**R 282**
	Moderate (OVD2)	**R 165**	**R 170**	**R 181**	**R 200**	**R 346**
	Dense (OVD3)	**R 210**	**R 216**	**R 231**	**R 255**	**R 443**
D3: VERY SCATTERED (3.05%)	Slight (OVD1)	**R 432**	**R 445**	**R 474**	**R 525**	**R 886**
	Moderate (OVD2)	**R 461**	**R 475**	**R 507**	**R 561**	**R 949**
	Dense (OVD3)	**R 505**	**R 521**	**R 555**	**R 614**	**R 1 043**
D4: SCATTERED (15.05%)	Slight (OVD1)	**R 1 899**	**R 1 959**	**R 2 088**	**R 2 310**	**R 3 828**
	Moderate (OVD2)	**R 1 925**	**R 1 986**	**R 2 116**	**R 2 341**	**R 3 883**
	Dense (OVD3)	**R 1 964**	**R 2 025**	**R 2 159**	**R 2 388**	**R 3 966**
D5: MEDIUM (37.55%)	Slight (OVD1)	**R 4 949**	**R 5 104**	**R 5 440**	**R 6 018**	**R 9 764**
	Moderate (OVD2)	**R 4 968**	**R 5 123**	**R 5 460**	**R 6 041**	**R 9 805**
	Dense (OVD3)	**R 4 996**	**R 5 153**	**R 5 492**	**R 6 076**	**R 9 866**
D6:DENSE (62.55%)	Slight (OVD1)	**R 8 781**	**R 9 056**	**R 9 652**	**R 10 679**	**R 16 982**
	Moderate (OVD2)	**R 8 793**	**R 9 068**	**R 9 665**	**R 10 693**	**R 17 006**
	Dense (OVD3)	**R 8 810**	**R 9 086**	**R 9 683**	**R 10 714**	**R 17 043**
D7: CLOSED (87.55%)	Slight (OVD1)	**R 13 107**	**R 13 518**	**R 14 407**	**R 15 940**	**R 24 902**
	Moderate (OVD2)	**R 13 111**	**R 13 522**	**R 14 411**	**R 15 944**	**R 24 910**
	Dense (OVD3)	**R 13 116**	**R 13 527**	**R 14 417**	**R 15 951**	**R 24 922**

Table 4.6 shows the total costs per hectare for the cheapest ground clearing method at each specific work rate combination, given the assumptions of Scenario 1, as discussed. Table 4.6 shows the ABBA method is still not an option at all combinations when compared with both ground clearing strategies.

Table 4.7 shows that the drill and fill strategy carries a lower cost/ha in relation to the drill and fill clearing strategy at all combinations as the original scenario which can again be attributed to the lighter weight of the drill equipment for the operators. The effects of the walk time component can especially be seen in Table 4.7 at a tree density D1 and dense OVD, as at this combination operators spend a larger proportion of their time walking than treating the trees such that the effects of OVD have more of an influence on a ground methods total costs per hectare.

Table 4.7: Summary of cost differences of Scenario 2 outputs

Density Class	Additional Chainsaw Felling time costs (R/ha)	Slight (OVD1) (R/ha)	Moderate (OVD2) (R/ha)	Dense (OVD3) (R/ha)	Additional Drill and Fill Herbicide Costs (R/ha)
D1	1.15	5.44	15.73	51.44	0
D2	43.15	5.41	15.65	51.19	2
D3	259.40	5.27	15.25	49.88	9
D4	1279.06	4.62	13.36	43.71	58
D5	3192.14	3.40	9.82	32.13	200
D6	5312.98	2.04	5.90	19.29	438
D7	7442.43	0.68	1.96	6.40	759

Table 4.7 additionally shows that the drill and fill strategy dominated the chainsaw strategy at all tree density classes. This result can be attributed to the higher productivity of the drill and fill team which resulted in the chainsaw strategy incurring a higher cost per hectare due to the higher chainsaw felling times at all combinations compared to the drill and fill strategy. Although the additional chainsaw operators led to a significant reduction in the additional felling time cost per hectare compared to the original scenario, the higher amount of productive workers in the drill and fill team resulted in the drill and fill strategy as the most financially attractive strategy at all combinations.

4.5 Scenario 2: Modelling outcome with accessibility

Scenario 2 is the alteration of the *original model*, except that the 'accessibility' component is now considered, which alters only two components: firstly, an increase in the estimated person days for both ground team methods as time can be lost in reaching and leaving a site which causes extended working times and secondly the cost of transport both on the first and return trip. The purpose of these scenarios would allow one to determine how the ground clearing methods total costs/ha will compare with that of the ABBA method which has significantly faster access times compared to ground teams.

In the 'Output Tables' sheet, the changes are entered into the 'access factor table'. It must be noted both the walk and drive time components are entered as one-way times in the model, however the model also accounts for the return trip in the calculations. The addition of the walk and drive time factors are linked to their specific factor increases, which increase the original total Nbal person days of each ground team method accordingly, while the total transport cost including return trip cost is also calculated according to a specific R/km current tariff for both normal and HATs. The changes made will influence the total costs/ha of both ground-based methods. Both the drive and walk time amounts were validated by communication with normal and high-altitude clearing specialists with the needed practical knowledge.

4.5.1 Scenario 2.1: A 30-minute drive time and 60-minute walk time

For the second scenario, as discussed in Section 4.2, a 30-minute drive time and 60-minute walk time was allocated to both ground-based methods. A one way 60-minute walk time was added by selecting the 'Easy' walking difficulty factor while the drive time is calculated automatically in the model as this remains unchanged in both access scenarios. The impact of these accessibility factors on the cheapest ground methods costs/ha is shown in Table 4.8 at each specific work rate combination. The additional walk and drive time amount was also validated by communication with specialists as being within the bounds of a realistic situation.

Table 4.8 shows that, with the addition of the influence of the accessibility component the helicopter clearing strategy does not become the most financially attractive strategy under all combinations. The significantly higher hourly cost of the helicopter makes the ABBA method prohibitively expensive. Figure 4.1 however shows that compared to the cheapest ground clearing strategy under site combinations displaying a tree density of D1 (Rare), dense OVD and at slope class 4 (45°) the ABBA method starts to incur a similar cost to the drill and fill strategy which will be explained in Scenario 2.2.

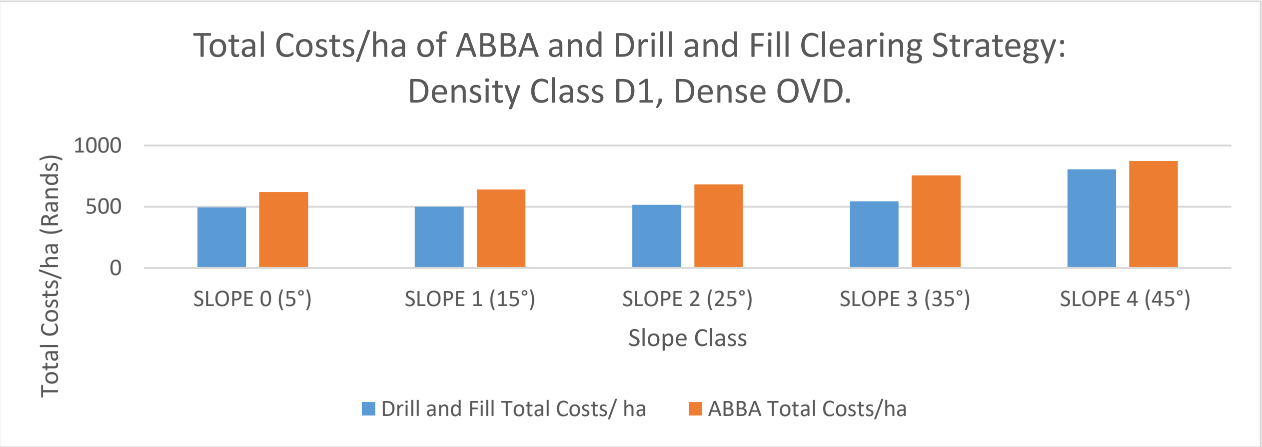

Figure 4.1: Cost comparison between drill and fill and the ABBA method at site combination D1, OVD3 at each slope class

Table 4.8: Costs per hectare at each site combination with 'Easy' access factor added

HELICOPTER	
CHAINSAW	
DRILL AND FILL	

D1: RARE (0.01%)	Slight (OVD1)	R	377	R	381	R	389	R	403	R	558
	Moderate (OVD2)	R	424	R	429	R	440	R	459	R	657
	Dense (OVD3)	R	493	R	501	R	517	R	544	R	807
D2: OCCASIONAL (0.51%)	Slight (OVD1)	R	460	R	467	R	480	R	504	R	730
	Moderate (OVD2)	R	507	R	514	R	531	R	560	R	830
	Dense (OVD3)	R	576	R	586	R	608	R	645	R	979
D3: VERY SCATTERED (3.05%)	Slight (OVD1)	R	893	R	913	R	956	R	1 031	R	1 626
	Moderate (OVD2)	R	939	R	960	R	1 006	R	1 086	R	1 723
	Dense (OVD3)	R	1 006	R	1 030	R	1 081	R	1 168	R	1 868
D4: SCATTERED (15.05%)	Slight (OVD1)	R	3 003	R	3 089	R	3 275	R	3 596	R	5 942
	Moderate (OVD2)	R	3 042	R	3 129	R	3 318	R	3 644	R	6 027
	Dense (OVD3)	R	3 102	R	3 191	R	3 384	R	3 716	R	6 154
D5: MEDIUM (37.55%)	Slight (OVD1)	R	7 513	R	7 732	R	8 207	R	9 025	R	14 760
	Moderate (OVD2)	R	7 542	R	7 762	R	8 239	R	9 061	R	14 822
	Dense (OVD3)	R	7 586	R	7 807	R	8 287	R	9 114	R	14 916
D6:DENSE (62.55%)	Slight (OVD1)	R	12 679	R	13 060	R	14 144	R	15 566	R	25 139
	Moderate (OVD2)	R	12 697	R	13 078	R	14 163	R	15 587	R	25 176
	Dense (OVD3)	R	12 723	R	13 105	R	14 192	R	15 619	R	25 232
D7: CLOSED (87.55%)	Slight (OVD1)	R	18 602	R	19 161	R	20 370	R	22 713	R	36 231
	Moderate (OVD2)	R	18 608	R	19 167	R	20 377	R	22 720	R	36 244
	Dense (OVD3)	R	18 617	R	19 176	R	20 386	R	22 731	R	36 262

4.5.2 Scenario 2.2: Accessibility: 60-minute walk time added to scenario 2

Scenario 2.2 is the same as Scenario 2.1, except that an additional 60 minutes' walk time component is added and hence only the increase in the walk time factor will have an influence on the costs/ha in relation to Scenario 2.1. Thus, in this scenario, the total one way walk time is increased from 60 minutes to 120 minutes by selecting the 'Difficult' walking difficulty factor into the access factor table, while a drive time of 30 minutes remains unchanged as in Scenario 2.1. The additional walk and drive time amount was also validated by communication with specialists as being within the bounds of a realistic situation. The impact of these accessibility factors on both ground methods costs/ha at density class D1 is shown in Figure 4.8 at each specific work rate combination.

Table 4.9 shows that under a combination of dense OVD and increasing slope, the helicopter provides the cheapest clearing strategy at OVD3 and slope class 4 (45°). As shown in Figure 4.2, this can be attributed to the benefits of the helicopter which can significantly improve or lower both the overall time of walking through a site for ground teams which takes longer in areas of dense OVD and increasing slope, while additionally being able to access an area significantly faster which prevents the extension of working times taking place as time is lost in reaching a site on foot.

Additional key contributing factors are the effects of the 'walking time' component at density class D1 and the helicopters faster site coverage over these areas compared to ground teams. In Figure 4.2, one can see that a large percentage of the time spent on site consists of ground teams walking between trees, compared to tree felling or poisoning time which commences at the higher density classes.

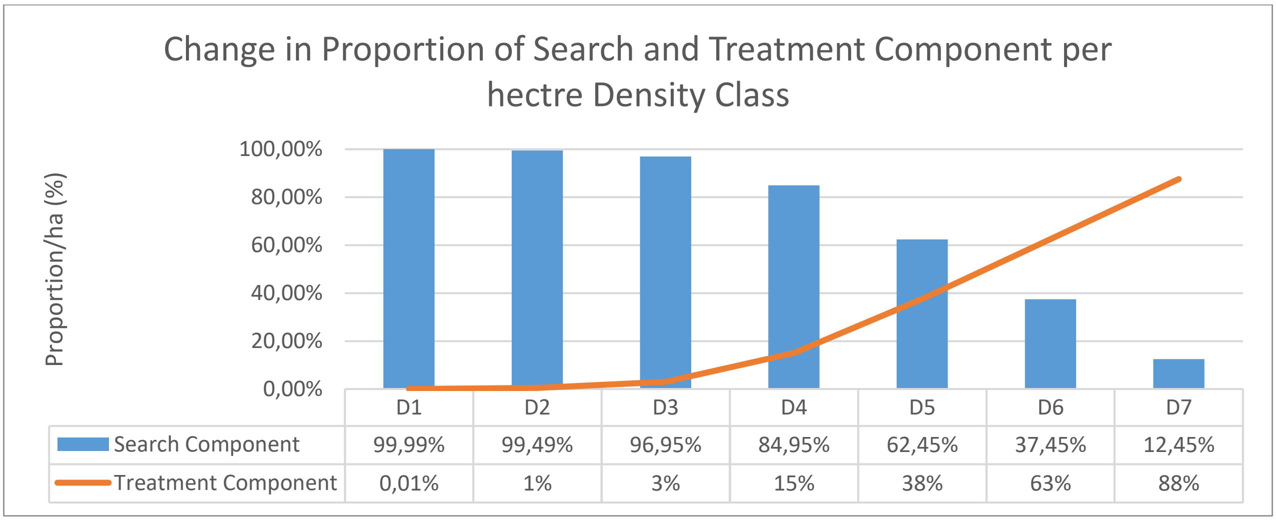

Figure 4.2: Change in walk and treatment time components per hectare density class

As shown above in Figure 4.2, density class D1 is characterized by very low tree populations. Ground teams thus allocate most of their effort walking the site compared to actual removal, such that an increase in OVD has a greater effect on overall work time at density class D1 compared to the higher classes.

Table 4.9: Costs per hectare at the 'Rare' (D1) density class for each site combination with 'Difficult' access factor added

HELICOPTER	
CHAINSAW	
DRILL AND FILL	

		SLOPE 0 (5°)	SLOPE 1 (15°)	SLOPE 2 (25°)	SLOPE 3 (35°)	SLOPE 4 (45 °) HATs
D1: RARE (0.01%)	Slight (OVD1)	R 440	R 445	R 458	R 479	R 692
	Moderate (OVD2)	R 511	R 519	R 536	R 566	R 845
	Dense (OVD3)	R 618	R 629	R 653	R 696	R 875
D2: OCCASIONAL (0.51%)	Slight (OVD1)	R 563	R 573	R 593	R 629	R 950
	Moderate (OVD2)	R 634	R 646	R 671	R 715	R 1 102
	Dense (OVD3)	R 740	R 755	R 788	R 844	R 1 330
D3: VERY SCATTERED (3.05%)	Slight (OVD1)	R 1 202	R 1 231	R 1 295	R 1 406	R 2 287
	Moderate (OVD2)	R 1 271	R 1 303	R 1 371	R 1 490	R 2 435
	Dense (OVD3)	R 1 375	R 1 410	R 1 485	R 1 616	R 2 657
D4: SCATTERED (15.05%)	Slight (OVD1)	R 4 281	R 4 407	R 4 680	R 5 150	R 8 985
	Moderate (OVD2)	R 4 342	R 4 469	R 4 747	R 5 224	R 9 115
	Dense (OVD3)	R 4 432	R 4 563	R 4 846	R 5 335	R 9 309
D5: MEDIUM (37.55%)	Slight (OVD1)	R 10 611	R 10 928	R 11 612	R 13 051	R 21 702
	Moderate (OVD2)	R 10 656	R 10 973	R 11 661	R 13 105	R 21 797
	Dense (OVD3)	R 10 722	R 11 042	R 11 735	R 13 186	R 21 940
D6:DENSE (62.55%)	Slight (OVD1)	R 18 053	R 18 594	R 20 025	R 22 045	R 36 707
	Moderate (OVD2)	R 18 080	R 18 622	R 20 054	R 22 078	R 36 764
	Dense (OVD3)	R 18 120	R 18 663	R 20 098	R 22 127	R 36 850
D7: CLOSED (87.55%)	Slight (OVD1)	R 26 260	R 27 042	R 28 736	R 31 656	R 52 141
	Moderate (OVD2)	R 26 268	R 27 051	R 28 746	R 31 667	R 52 160
	Dense (OVD3)	R 26 282	R 27 065	R 28 760	R 31 683	R 52 188

Additionally, as shown in Figure 4.3, an increase in slope further increases these effects of OVD on walking times and thus the total costs/ha through the increase in the area to be searched. This is especially the case at slope class 4 (45°) where high altitude clearing teams (HATs) are required. HAT personnel, due to the higher skills needed compared to normal teams afford a higher daily wage, and the additional rope access equipment results in a higher cost/ha compared to normal teams. Under these conditions with difficult site accessibility, HATs spend a significant amount of their time in reaching a site which add to an extension of their working times as time is lost in reaching the site which further increases the clearing costs of these teams. The ABBA method becomes the most financially attractive strategy under these site conditions displaying very low tree density and difficult site access compared to ground teams as the helicopter is significantly faster both in terms of covering ground at sites having these large walk time proportions and accessing sites having difficult accessibility.

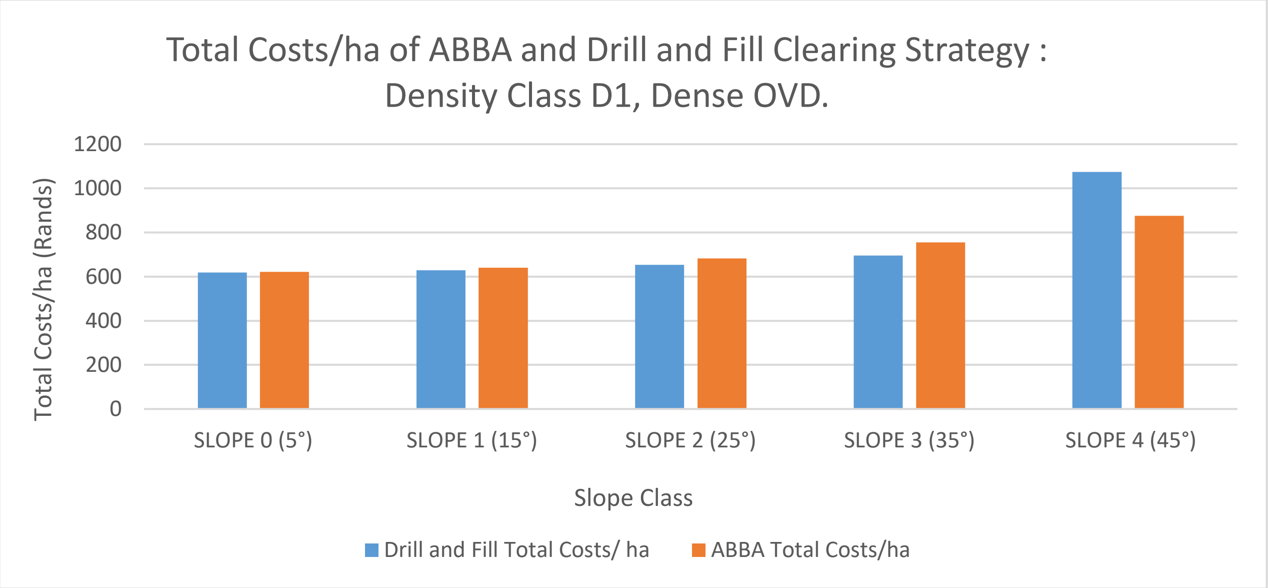

Figure 4.3: Cost comparison between cheapest ground method (drill and fill) and the ABBA method at site combination D1, OVD3 at each slope class.

4.6 Conclusion

The work rate model was constructed in Chapter 3 to determine and compare the costs per hectare of the traditional chainsaw clearing method with that of the two chosen novel methods. The purpose of the model was to determine which control method was the cheapest at the various site combinations based on their respective costs per hectare. Prioritization of clearing sites can be environmentally complex and decision tools which help prioritise these complexities which vary from site to site has been recognised as an area of need for management.

The first scenario comprised of a typical chainsaw clearing team currently being used in practice compared with a hypothetical drill and fill team while the ABBA method was also compared against these ground clearing methods. The results showed that the drill and fill method has a lower wage and PPE daily rate from the added safety of the method compared to felling. The drill and fill method however experiences a higher tools and equipment daily rate from the added drill equipment per operator and a higher herbicide cost compared to the chainsaws variable costs (fuel, oil, maintenance, and cutter spares) per hectare. The drill and fill method however still incurred the lowest cost per hectare at all site combinations despite these higher cost components. This lower cost/ ha of the drill and fill method at all site combinations was attributed to the drill and fill methods added safety which led it to having a much higher productivity compared to the chainsaw team as the method is much safer compared to felling, such that no supervision is needed per operator compared to the chainsaw method which places limitations on its productivity. This result was also experienced despite when the maximum allowable amount of four chainsaw operators in a team was run through the model which can again be attributed to the significantly higher productivity of the drill and fill team from the aforementioned safety benefits of this method.

The ABBA method was only the most financially favourable method at site combinations which experience ‘difficult’ access, dense OVD and a ‘Rare’ (D1) tree density class. At these site combinations a high proportion of walk time is present at the Rare (D1) tree density class and thus ground operators spend a significantly high proportion of their work time walking a site than actually removing or treating trees and OVD density also has more of an influence on a ground methods total costs per hectare. When sites are additionally remote and difficult to access, ground teams spend a larger proportion of their time in accessing a site which can lead to an extension of working times on site which increases costs. The helicopter affords the added advantage at these site combinations from its faster ground coverage, especially in dense OVD, and faster access times to a site which makes it the most financially favourable at these site combinations. It must be noted however that spraying in these mountainous areas often incur unfavourable weather conditions which make it too risky for the operators and the helicopter thus stands idle for long periods which makes this method more expensive as less hours can be achieved per year which can make the method financially non-viable. In order to prevent this taking place government must therefore make use of a private contractor involved in agricultural crop spraying which can allow ‘cross subsidisation’ to take place as operations can be diverted to low lying agricultural crop spraying when conditions for ABBA spraying are unfavourable allowing more hours to be worked per year and lowering its overall cost.

Chapter 5: Conclusions, Summary and Recommendations

5.1 Conclusions

Invasive pines are thriving within the rugged mountainous areas of the Western Cape fynbos. These complex heterogeneous environments present significant challenges to clearing operations in terms of tree density, slope, surrounding obstructive vegetation and remoteness. These properties often result in longer walk, removal and site access times which can significantly increase overall costs of labour-intensive methods such as felling. Although felling has been the main clearing method thus far, it has become too expensive and too slow in comparison with the speed of invasion and the problem is continuing to get worse over time. Chemical methods such as the drill and fill method, and the aerial basal bark application (ABBA) method, which have proved successful in other countries have not been tested for local conditions. Although, the use of helicopters intuitively overcome many of the limitations of ground teams (such as slow ground coverage and site access) the high hourly rate of helicopters fuels perceptions that the method remains prohibitively expensive. The drill and fill method seems to be more productive compared to felling, although the direct cost still needs to be verified for South African conditions. The aim of this study was to determine under what site conditions these chemical control methods and the use of helicopters would be more cost effective compared to traditional felling.

The study showed that the higher productivity of drill and fill teams outweighs their higher total daily team rate compared to traditional felling. The productivity of last mentioned is hampered by mandatory requirements such as higher safety and supervision associated with chainsaw operations, causing the inclusion of unproductive team members, in contrast with all members of a drill and fill team using a drill. The relative lower weight of drill and fill equipment decreases walk times and increases productive working time. Consequently, most scenarios have shown that the drill and fill method is more cost-effective compared to traditional felling.

The ABBA method proved the preferred method for more extreme cases where isolated pines situated in dense fynbos with difficult site access at slope gradients of 45° are targeted. All these factors lead to the longer walk times of ground teams which decreases their productivity to such an extent that ABBA is comparatively more cost-effective. Furthermore, at slope gradients of 45° and higher, high-altitude teams require specialized equipment which decreases their productivity even further. Helicopters should therefore be reserved to target the species in its isolated spread stage before it reaches reproductive maturity which have the potential of spreading large amounts of wind-blown seeds over large distances.

The hourly cost of the helicopter applied in this study assumes a high level of use of the available hours per annum. This is only possible if a helicopter can be used for a variety of tasks in various places to avoid being stranded in one place, due to unfavourable wind conditions. A helicopter of a contractor used for both crop spraying in agricultural areas and invader tree eradication in mountainous areas can therefore work at a lower hourly rate than a government owned helicopter obtained only for invader tree eradication.

5.2 Summary

Aerial and ground based chemical methods have increased the efficiency and scope of invasive Pine removal in other countries however no such study exists on their relative costs compared to current labour-intensive approaches and more specifically, the cut-off points in terms of tree density, accessibility, and surrounding vegetation. Chapter 1 states the aim of the study was to identify the site conditions where the ABBA and drill and fill method would be preferred in terms of costs over traditional felling which would help inform the current integrated approach for managing the species in South Africa.

To achieve this aim of the study, several objectives were set out. These objectives involved: to adapt the current ground-based AIP work rate model, obtain a total cost of clearing for traditional methods at different site combinations using current AIP clearing data, work rates and cost estimates for the alternative methods under the same site conditions.

Chapter 2 presented the literature review. South Africa's alien invasive pine problem was presented, and current traditional pine clearing methods were discussed. Two alternative control methods were then introduced, being the ABBA and drill and fill method, which is then compared to traditional felling later in the study. Including these methods could result in an integrated solution for management of the species which has been lacking and where traditional approaches have become too expensive and ineffective.

Chapter 3 provided an in-depth explanation as to how current work rate variables: tree density, slope, obstructive surrounding vegetation (OVD) and accessibility were adapted and incorporated into a work rate matrix for each of the control methods. The matrix was then applied to the ground-based methods: felling and the drill and fill method. Both methods daily rates were disaggregated into their relevant personal protective equipment (PPE), wages and equipment rates and their relevant team compositions were discussed. Felling team compositions and cost data for the high altitude-based teams did not exist, therefore assumptions regarding typical high altitude clearing team compositions and daily rates were identified and validated through discussions with relevant high altitude clearing operations and specialized remote access team managers. Cost data for these teams included: PPE, wages and equipment including specialized rope equipment. To include the drill and fill method in the model, no such work rates or cost data existed nationally and as such assumptions were made on the methods relevant poisoning time, team composition and wage rate. PPE and equipment items were constructed from New Zealand drill and fill best practice guidelines and adapted from current national AIP cost data.

Chapter 4 presents the results and findings and outlines the financial comparisons of the clearing methods. Key observations were highlighted for various site combinations. The original model results were firstly presented which consisted of a typical chainsaw clearing team versus a standard drill and fill clearing team and the ABBA method. Alterations were made to the original model in the form of scenarios which differed in terms of team composition for the ground clearing methods and site access time between all three methods. Three scenarios were simulated which compared the most financially viable option between each of the three methods.

The original result consisted of a standard chainsaw clearing team which included one chainsaw operator and a fully dedicated drill and fill team of eleven drill and fill operators. The results showed that, although the chainsaw had a lower treatment time and total daily rate compared to the drill and fill team, the drill and fill team was more cost-effective because of higher productivity resulting from faster walk times and more productive team members per team. The first scenario comprised of the maximum allowable number of productive workers within the chainsaw and drill and fill teams respectively, while the ABBA method remained the same as in the original model. The first scenario thus incorporated three additional chainsaw operators due to the risks in terms of worker safety from felling which gave a total of four chainsaw operators in a team. The drill and fill team had an additional two operators added due to the technique being significantly safer and requiring minimal supervision compared to felling which resulted in a dedicated drill team of thirteen drill operators. These changes were replicated throughout the model and the costs per hectare of each method of Scenario 1 was recorded. From the results, the drill and fill method was the most financially favourable method despite the increased productivity of the chainsaw team from the added operators.

Scenarios 2 and 3 were then tested with the purpose of allowing one to determine the effects site access has on the total costs per hectare between the ground methods and the ABBA method which included a 60- and 120-minute walk time added to the ground clearing methods respectively and a 30-minute drive time in both, with all quoted as one way in the model although the return leg is also calculated automatically. Site access increases ground clearing costs as time is lost in reaching and leaving the site which leads to an extension of working times and secondly the cost of transport both on the first and return trip. Site access was applied to the model and the changes observed. The results showed that the drill and fill clearing strategy remained the most favourable clearing option in Scenario 1 which included ‘Easy’ access time at a 60-minute walk time and 30-minute drive time. The results of Scenario 2, which included a ‘Difficult’ access time of 120-minute walk time and 30-minute drive time however showed the ABBA method became the most financially favourable method at site combination of ‘Rare’ tree density class, dense OVD and at a high slope gradient of 45°.

5.3 Recommendations

In terms of the main findings of the research it is recommended to:

- replace all felling teams with drill-and-fill teams
- employ helicopters for remote areas with “rare” density, slopes of 45° or higher, and difficult underfoot conditions

It is also recommended to conduct field trials on the drill and fill and ABBA method to verify its effectiveness under Western Cape / South African conditions.

In practice work rates exist for normal ground teams, however as mentioned by high altitude team managers in the field, the accuracy of high-altitude team costings could be improved by incorporating work rate standards for these teams. It is therefore recommended that these high-altitude work rates should be measured in practice and incorporated in the future for these teams.

The field trails should give special attention to herbicide selection and dosage for the ABBA and drill and fill methods. The use of the ‘volume and location tool’ (VAL2) should also be incorporated, as the tool would aid practitioners in finding suitable herbicide doses at a lower cost, while also allowing effective monitoring to take place for the species by management which is lacking in current clearing programmes.

The model can be improved by further research on the influence on obstructive vegetation density (OVD) on productivity.

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Annexures

Annexure A: Felling (right) and 'kill standing approach' (left) comparison on native vegetation regeneration.

Source: Macalister & Stein 2013

Annexure B: Drill and fill operator PPE, tools and equipment list.

1. DRILL AND FILL MATERIALS

1.1 EQUIPMENT RECOMMENDATIONS

Below are recommendations for equipment for set-up and delivery.

EQUIPMENT TYPE	RECOMMENDATIONS	IMPORTANT CONSIDERATIONS
Drilling	• 18 V drill with a 13-18 mm wood bit or auger. • Petrol-powered mechanised drill (fitted with a 20 mm auger bit).	Petrol-powered drills should not be used in environments where there is a fire risk.
Application	• A bottle fitted with a nozzle • A backpack applicator (to be used where conditions allow)	Bottles must be labelled. Backpack applicator should only be used where open conditions allow. All application equipment must comply with the Health and Safety at Work (Hazardous Substances) Regulations 2017.
Personal Protective Equipment (PPE)	• Safety glasses (used when using Metsulfuron Methyl or Glyphosate) • Chemical googles (used when using neat Tordon Pasture boss or equivalent (360 g/L triclopyr amine + 30 g/L aminopyralid)) • Chemical gloves (>14 mils) • Cotton overalls (buttoned to the neck and wrist) • Waterproof boots	Personal Protective Equipment (PPE) must be used in handling, mixing, application and cleaning of herbicides and associated equipment. See the Safety Material Data Sheet.
Other	• A spill kit with a minimum capacity of 20-litre • A 400g fire extinguisher (in high • A First Aid kit with saline eye wash must be available for operators	Wherever the fire risk is above 'Low' on the Fire Danger Class System, fire extinguishers must be used.

4 | GROUND-BASED HERBICIDE INJECTION – 'DRILL AND FILL'

Annexure C: Table used by Working for Water for mapping the density of adult Pinus species.

Standardized Density Class	Percent Cover Range (Descriptive)	Midpoint Cover	Plants/ ha Range
1	Rare (< 0.01%)	0,01%	0.5 -1
2	Occasional (0.02%- 1.0%)	0,51%	1 - 25
3	Very Scattered (1.1%- 5%)	3,05%	25 - 225
4	Scattered (5.1%-25%)	15,05%	225 - 1200
5	Medium (25.1%-50%)	37,55%	1200 - 4300
6	Dense (50.1 %-75%)	62,50%	4300 - 7600
7	Closed (75.1%-100%)	87,55%	>7600

Annexure D: Cost components forming part of a contractor's quotation package.

Working for Water

Contract #

Category	Contractor's Costs	% of Total quotation costs
Total wage cost to clear site	A	A / I x 100
Unemployment Insurance Fund (UIF) (1% employees wages + 1% from employer)	B	B / I x 100
Capital Build-up	C	C / I x 100
Rations / Camping Allowance	D	D / I x 100
Personal Protective Equipment	E	E / I x 100
Tools and Equipment	F	F / I x 100
Transport	G	G / I x 100
Administration	H	H / I x 100
Sub -Total	I	
VAT (14%) (supply latest VAT payment certificate)	J	
TOTAL QUOTATION COSTS	K	add-up all the above %

I declare that all the work will be done in accordance with the Working for Water Operational Standards and Rules and Regulations that I've signed when registering with the Working for Water Programme. I also declare that the applicable contract boundaries have been shown to me infield by a WfW Manager. I further agree to eradicate all alien species within the contract area boundaries. This quotation is based on my own estimations for the task, I was not influence and/or forced by any WFW Management personnel, and therefore agree to complete the task in full.

Contractor	Signature	Date
WfW Project Manager	Signature	Date
Area / IA / Cluster Manager	Signature	Date

Annexure E: Standardized Working for Water ground team composition for contract generation.

As described in Norm Table	**Initial Clearing**	1 x Contractor or Supervisor
		1 x Chainsaw Operator
		1 x Herbicide Applicator
		1 x H&S Worker
		1 x 1st Aid Worker
		2 x Peer Educators
		5 x General Workers

Annexure F: Working for Water (WfW) PPE, tools and equipment lists per job type.

PPE and Tools & Equipment List per WfW job category

Herbicide applicator		
Description	Lifetime	Quantity
Blue overall (jacket & trousers)	1	2
Safety boots (carbon/steel toe cap)	1	1
Hard hat	1	1
Knapsack sprayer	2	1
Knapsack Maintenance	1	1
Safety goggles (eye protection)	1	1
Rubber gloves elbow length	1	2
Gumboots (steel toe cap)	2	1
Capes (head, shoulders & back)	1	2
Capes (head, shoulders & back)	1	2
Masks (FFP2) (48/yr = 4/mnth)	0.08	4
Leggings	1	1
Rainsuit (jacket & trousers)	1	1
Jugs, bucket	1	2
Plastic Container 25l	2	1

Contractor	
Description	Lifetim
Blue overall (conti suit)	1
Safety boots (carbon/steel toe cap)	1
Hard hat	1
First aid box + contents replacement	1
Spade	5
Fire beaters	3
Wajax can	5
Towel, Toilet Paper, Hazard Tape, etc	1

Chainsaw operator		
Description	Lifetime	Quantity
Blue overall (conti suit)	1	2
Safety boots (carbon/steel toe cap)	1	1
Safety helmet EU standard	1	1
Safety pants EU standard 11 layers	1	2
Chainsaw gloves	1	2
Webbing belt	2	1
Whistle	5	1
Combi can	2	1
Fire extinguisher	5	1
Fire extinguisher maintenance	1	1
Chainsaw (Stihl MS 382)	2	1
Chainsaw maintenance (INCLUDE OIL & FUEL)	1	1
Pressure bandage	1	2
Sharpening kit	1	1
Sharpening kit tool pouch	1	1

General Worker	
Description	Lifetime
Blue overall (jacket & trousers)	1
Safety boots (carbon/steel toe cap)	1
Hard hat	1
Harness (for equipment)	2
Leather gloves (wrist length)	1
Rubber gloves (short)	1
Lopping shears	1
Pruning Saw	1
Pruning Saw maintenance	1
Safety goggles (eye protection)	1
Rainsuit (jacket & trousers)	1
Axe (Hatchet)	1
Axe maintenance	1
Spray can (hand held)	1
Spray can (hand held) maintenance	1
Gumboots (steel toe cap)	2

Note: 1 year = 186 working days

Annexure G: Excel spread sheet showing the daily rate of each job role used for calculating the total daily PPE and equipment rate for a clearing team.

PERSONAL PROTECTIVE EQUIPMENT (PPE) AND TOOLS LIST

PERSONAL PROTECTIVE EQUIPMENT (SAFETY)

Calculation of daily rate done according to Working for Water (WFW) guidelines:
Personal Protective Equipment for each specific job type Obtained from WFW PPF Tools and Equipment H & S Standards and Work Methods.

$$\frac{Price\ of\ Item \times Quantity}{Lifetime\ in\ Years \times Working\ Days\ Per\ Year}$$

CONTRACTOR

Item	Items Lifetime (Years)	Quantity Per Year	Price per Item (April 2015)	Price per Item (April 2019)		Cost/ Year	Cost/ Month	Cost / Day
PERSONAL PROTECTIVE EQUIPMENT								
Blue Overalls	1	2	118.1	144.1723497		288.3446995	24.02872495	1.55024032
Safety Boots (Carbon/ Steel toe Cap)	1	1	306.95	374.7138251		374.7138251	31.22615209	2.014590458
Hard Hat	1	1	24.15	29.48147541		29.48147541	2.456789617	0.158502556
					Total R	**692.54**	**57.71166667**	**3.723333333**
EQUIPMENT AND MAINTENANCE								
First Aid box	1	1	532.41	649.9475082		649.9475082	54.16229235	3.494341442
Maintenance First Aid Kit	1	1	295.78	361.0778798		361.0778798	30.08982332	1.941278924
Spade	5	1	100.93	123.2118142		24.64236284	2.053530237	0.132485822
Fire Beaters	3	1	120.68	147.3219235		49.10730783	4.092275653	0.264017784
Wajax Can	5	1	1082.02	1320.892175		264.178435	22.01486958	1.420314167
Towel, Toilet Paper, Hazard Tape etc	1	1	532.41	649.9475082		649.9475082	54.16229235	3.494341442
					Total R	**1998.901002**	**166.5750835**	**10.74677958**

HIGH ALTITUDE TEAM

GENERAL WORKER *(Includes H& S Worker, Peer Educators, First Aider as Same PPE and Equip as General Workers).*

Item	Items Lifetime (Years)	Quantity Per Year	Price per Item (April 2015)	Price per Item (April 2019)		Cost/ Year	Cost/ Month	Cost / Day
PERSONAL PROTECTIVE EQUIPMENT								
Blue Overall (Jacket and Trousers)	1	2	118.1	144.1723497		288.3446995	24.02872495	1.55024032
Safety Boots (Carbon/ Steel Toe Cap)	1	1	306.95	374.7138251		374.7138251	31.22615209	2.014590458
Hard Hat	1	1	24.15	29.48147541		29.48147541	2.456789617	0.158502556
Leather Gloves (Wrist Length)	1	4	32.96	40.2364153		160.9456612	13.41213843	0.865299254
Rubber Gloves (Short Length)	1	2	18.33	22.37662295		44.7532459	3.729437158	0.240608849
Safety Goggles (Eye Protection)	1	1	35.12	42.87326776		42.87326776	3.572772313	0.23050144
Raincoat (Jacket and Trousers)	1	1	89.85	109.6857377		109.6857377	9.140478142	0.589708267
Gumboots (Steel Toe Cap)	2	1	177.48	216.661377	**Total R**	**1050.797913**	**87.56649271**	**5.649451143**
EQUIPMENT AND MAINTENANCE								
Equipment Harness	2	1	500.39	610.858612		305.429306	25.45244217	1.642093043
Lopping Shears	1	1	986.23	1203.955093		1203.955093	100.3295911	6.472876844
Pruning Saw	1	1	595.89	727.4416721		727.4416721	60.62013934	3.910976732
Pruning Saw Maintenance	1	0.17	425.9	519.9238251		86.65397086	7.221164238	0.465881564
Axe	1	1	112.15	136.9087978		136.9087978	11.40906648	0.736068805
Axe Maintenance	1	0.17	208.18	254.1388634		42.35647723	3.529706436	0.227722996
Spray Can	1	1	102.25	124.823224		124.823224	10.40193534	0.671092602
Spray Can Maintenance	1	0.17	35.5	43.33715847		7.222859745	0.601904979	0.038832579
					Total R	**2634.791401**	**219.5659501**	**14.166**

CHAINSAW OPERATOR

Item	Items Lifetime (Years)	Quantity Per Year	Price per Item (April 2015)	Price per Item (April 2019)		Cost/ Year	Cost/ Month	Cost / Day
PERSONAL PROTECTIVE EQUIPMENT								
Blue Overalls	1	2	118.1	144.1723497		288.3446995	24.02872495	1.55024032
Safety Boots (Carbon/ Steel toe Cap)	1	1	306.95	374.7138251		374.7138251	31.22615209	2.014590458
Chainsaw Helmet (EU Standard)	1	1	414.1	505.5187978		505.5187978	42.12656648	2.717842999
Safety Pants (EU Standard 11 Layers)	1	2	829.65	1012.807705		2025.61541	168.8012842	10.89040543
Chainsaw Gloves	1	2	215.15	262.6475956		525.2951913	43.77459927	2.824167695
Webbing Belt	2	1	59.16	72.22045902		36.11022951	3.009185792	0.194141019
Whistle	5	1	15.51	18.93406557		3.786813115	0.31556776	0.02035921
Pressure Bandage	1	2	18.56	22.65739891		45.31479781	3.776233151	0.243627945
					Total R	**3804.699764**	**317.0583137**	**20.45537507**
EQUIPMENT AND MAINTENANCE								
Combi Can	2	1	327.5	399.8005464		199.9002732	16.6583561	1.074732652
Fire Extinguisher	5	1	367.8	448.997377		89.79947541	7.483289617	0.482792879
Maintenance of Fire Extinguisher	1	1	163.24	199.2776831		199.2776831	16.60647359	1.071385393
Sharpening Kit	1	1	176.5	215.4650273		215.4650273	17.95541894	1.158414125
CHAINSAW	############################	1	7125	8697.95082		7280.184836	606.6820697	39.14077869
					Total R	**7984.627295**	**665.3856079**	**42.92810374**

HERBICIDE APPLICATOR

Item	Items Lifetime (Years)	Quantity Per Year	Price per Item (April 2015)	Price per Item (April 2019)		Cost/ Year	Cost/ Month	Cost / Day
PERSONAL PROTECTIVE EQUIPMENT								
Blue Overall (Jacket and Trousers)	1	2	118.1	144.1723497		288.3446995	24.02872495	1.55024032
Safety Boots (Carbon/ Steel Toe Cap)	1	1	306.95	374.7138251		374.7138251	31.22615209	2.014590458
Hard Hat	1	1	24.15	29.48147541		29.48147541	2.456789617	0.158502556
Rubber Gloves (Elbow Length)	1	2	35.96	43.89871038		87.79742077	7.31645173	0.472029144
Safety Goggles (Eye Protection)	1	1	35.12	42.87326776		42.87326776	3.572772313	0.23050144
Gumboots (Steel Toe Cap)	2	1	177.48	216.661377		108.3306885	9.027557377	0.582423057
Raincoat (Jacket and Trousers)	1	1	89.85	109.6857377		109.6857377	9.140478142	0.589708267
Capes (Head, Shoulders and Back)	1	2	95.17	116.1802077		232.3604153	19.36336794	1.249249545
Masks (48/year= 4/ Month)	0.08	4	14.25	17.39590164		835.0033121	69.58360934	4.489265119
Leggings	1	1	160.79	196.2868087		196.2868087	16.35723406	1.055305423
					Total R	**2304.877651**	**192.0731376**	**12.39**
EQUIPMENT AND MAINTENANCE								
Knapsack	2	1	710.59	867.4634208		433.7317104	36.1443092	2.331890916
Knapsack Sprayer Maintenance	1	1	296.54	362.0056612		362.0056612	30.16713843	1.946266996
Jugs and Buckets	1	2	97.56	119.0978361		238.1956721	19.84963934	1.280621893
Plastic Container 25 litre	2	1	71.58	87.38236066		43.69118033	3.640931694	0.234898819
					Total R	**1077.624224**	**89.80201867**	**5.79**

Annexure H: The work rate matrix used for calculating the cost of each clearing method at each site combination.

HELICOPTER	
CHAINSAW	
DRILL AND FILL	

		SLOPE 0 (5°)	SLOPE 1 (15°)	SLOPE 2 (25°)	SLOPE 3 (35°)	SLOPE 4 (45 °) HATs
D1: RARE (0.01%)	CHAINSAW					
	DRILL AND FILL					
	HELICOPTER (ABBA)					
D2: OCCASIONAL (0.51%)	CHAINSAW					
	DRILL AND FILL					
	HELICOPTER (ABBA)					
D3: VERY SCATTERED (3.05%)	CHAINSAW					
	DRILL AND FILL					
	HELICOPTER (ABBA)					
D4: SCATTERED (15.05%)	CHAINSAW					
	DRILL AND FILL					
	HELICOPTER (ABBA)					
D5: MEDIUM (37.55%)	CHAINSAW					
	DRILL AND FILL					
	HELICOPTER (ABBA)					
D6:DENSE (62.55%)	CHAINSAW					
	DRILL AND FILL					
	HELICOPTER (ABBA)					
D7: CLOSED (87.55%)	CHAINSAW					
	DRILL AND FILL					
	HELICOPTER (ABBA)					

Annexure I: Wage Rates of the various clearing roles used in national clearing programmes.

2019/2020				
NRM Teams Wage Rates, Equipment & PPE Tariffs for calculating the maximum allowable price from 1 April 2018				
riffs are based on 186 days/year				
	Baseline daily equivalent task wage rate	Baseline daily equivalent task wage rate	Compensation for leave days (16%)	Minimum daily equivalent task wage rate
	2017/18	2018/19		
Contractor	R 294.35	R 308.77	R 49.40	R 358.15
or Supervisor	R 171.80	R 180.22	R 28.85	R 209.05
Chainsaw operator	R 114.22	R 120.25	R 19.20	R 146.35
Brushcutter operator	R 114.22	R 120.25	R 19.20	R 146.35
Herbicide applicator	R 96.41	R 101.50	R 16.20	R 123.50
	Including 1st Aider, H&S, Peer Educator			
General worker & Trainee Fi	R 91.05	R 95.90	R 15.30	R 116.70
Transport				
		4X2	4X4	
Transport rate/km (R.c)		R 4.30	R 5.05	
Minimum rate/day		R 137.60	R 161.60	based on a minimum distance of 32km/day
Rate for trailer per day		R 53.05	R 0.00	
Administration	R 77.85			
Sleep out Rate	R 62.37	R 65.65		
Catering	R 51.92	R 54.65		

WOF and HAT Daily Wage				
WORKING ON FIRE			Baseline daily Wage Rate	
Job Ranks	2017-2018	%	2018-2019	Leave Equivalent per Day (as per other NRM Programmes)
Fire Fighter	R101.84	5.30%	R107.24	R17.16
Brush Cutter Operator	R104.21	5.30%	R120.25	R19.24
Chain Saw Operator	R104.21	5.30%	R120.25	R19.24
First Aider	R104.21	5.30%	R107.24	R17.16
OHS Representative	R104.21	5.30%	R107.24	R17.16
Storekeeper	R118.42	5.30%	R124.70	R19.95
Herbicide Applicator	R103.56	5.30%	R107.24	R17.16
Base Communication Representative	R104.21	5.30%	R107.24	R17.16
Crew Leader Type 2	R206.06	5.30%	R216.98	R34.72
Crew Leader Type 1	R253.43	5.30%	R266.86	R42.70
Probationary Driver	R206.06	5.30%	R216.98	R34.72
Driver	R324.48	5.30%	R341.68	R54.67
Probation CL Type 2	R104.21	5.30%	R107.24	R17.16
Admin (Dev. position)	R206.06	5.30%	R216.98	R34.72
Type 3 Dispatchers	R260.53	5.30%	R274.34	R43.89
Assist Base Manager	R270.00	5.30%	R284.32	R45.49
HSV Allowance	R1 061.07	5.30%	R1 117.31	
AFHB Allowance	R1 342.92	5.30%	R1 414.09	
HAT PROJECTS				
Job Code	2017-2018	%	2018-2019	Leave Equivalent per Day (as per other NRM Programmes)
Rope Access Technicians (RAC)	R146.00	5.30%	R161.30	R25.81
Driver	R324.48	5.30%	R358.45	R57.35
Crew Leader (Driver)	R385.00	5.30%	R405.41	R64.86
Crew Leader	R253.34	5.30%	R279.80	R44.77
CL1 (Irata)	R329.00	5.30%	R346.44	R55.43
CL2	R206.06	5.30%	R216.98	R34.72
CL2 (Irata)	R290.00	5.30%	R305.37	R48.86
RAC/Base Communication Representati	R148.00	5.30%	R155.84	R24.94
First Aider (Non RAC)	R104.21	5.30%	R107.24	R17.16
Herbicide (Non RAC)	R103.56	5.30%	R107.24	R17.16
Brush Cutter (Non RAC)	R104.21	5.30%	R120.25	R19.24
Chainsaw Operator (Non RAC)	R104.21	5.30%	R120.25	R19.24
SHE (Non RAC)	R104.21	5.30%	R107.24	R17.16
Store Keeper	R118.42	5.30%	R124.70	R19.95
Probationary Driver	R206.06	5.30%	R216.98	R34.72
AFHB Allowance	R1 342.92	5.30%	R1 414.09	

Annexure J: Drill and fill drencher gun and dosing backpack quotation.

VetnetVeterinarySuppliescc t/a Vetnet cc

vetNET Quality Veterinary Instruments

ADDRESS		CONTACT	MAILING	www.vetnetcc.co.za
P O Box 1830	2 Wilger Road	Tel : (017) 811 5697	Orders: vetnet.sales@mweb.co.za	Import / Export # 1844979
Ermelo - 2350	Ermelo - 2351	Fax : 086 553 9167	Admin: vetnet-admin@mweb.co.za	Vat Nr: 4420191407
Mpumalanga - South Africa		Cell: 0817422089	Finance: vetnet@mweb.co.za	

ACCOUNT TO:	DELIVERY TO:	Quotation
Cash Sales (1)	Kyle Tel: 071 103 6142 E: kyleboast@hotmail.com	DOCUMENT NO: QU106992 DATE: 29/10/19 PAGE: 1

ACCOUNT	Your Ref	Tax Exmp	Tax Reference	Sales Code	Cost Code	
COD001	KYLE	N				Exclusive

Code	Description	Quantity	Unit	Unit price	Disc%	Tax	Nett price
200575	D/G Phil 20ml Auto (Container) PAD1232C	1.00	ea	2,149.00		15.00%	2,149.00
200895	D/G Phil Container (5 l) WX185	1.00	ea	608.00		15.00%	608.00

Quote's is only Valid for 60 days after quoting date.

Received in good order

SIGNATURE: ________________

DATE: ____________________ **NAME:** ______________________

Discount	0.00%	0.00
Amount excl tax		2,757.00
Tax		413.55
ZAR TOTAL		**3,170.55**

Annexure K: Drill and fill herbicide quotation.

QUOTATION

P O Box/Posbus 85
Wellington, 7654
3 Merchand Street, Wellington
Tel: (021) 873 6177
Fax/Faks: (021) 873 7606
Inteligro Pty Ltd
Reg. No 1996/004560/07
Vat No 4500178274

InteliGro
intelligent crop solutions

QUOTATION NUMBER
Q00004800

Customer. Vat No:

STELLENBOSCH CASH ACCOUNT (VAT)
POSBUS 85
WELLINGTON
7654

DELIVER TO:
SEBASTIAN BURGER

Comments: Kyle

INV DATE	CUST CODE	CUST O/N	DEL NOTE	DEL DATE	DEPOT	AGENT
02/04/2020	3STE22				Stellenbosch	BB3332

ITEM	DESCRIPTION	UNIT	QTY	UNIT PRICE	DISC. PRICE	AMT EXCL. VAT
REGL01-0	REGLONE	20 L	1	4,353.000	4,353.00	4,353.00

The supply of goods to the Customer on this invoice is subject to the General Terms & Conditions of Sale on the reverse-side of the Inteligro delivery note and shall not be subjected to any other terms and conditions whatsoever.

INTEREST WILL BE CHARGED ON OVERDUE ACCOUNTS IN ACCORDANCE WITH THE CREDIT AGREEMENT.

Die voorsiening van goedere aan die Kliënt op hierdie faktuur is onderhewig aan die Algemene Verkoopsterme en voorwaardes op die keersy van die Inteligro afleweringsnota en sal nie aan enige ander bepalings of voorwaardes onderhewig wees nie.

RENTE SAL GEHEF WORD OP AGTERSTALLIGE REKENINGE IN OOREENSTEMMING MET DIE KREDIET OOREENKOMS.

BANK DETAILS: STANDARD BANK; PAARL
ACC NO: 072175907; BANK CODE: 050210

SUB TOTAL	4,353.00
VAT	652.95
TOTAL	R 5,005.95

CASH INVOICE:
Please use Invoice ref number as payment reference

Annexure L: ABBA herbicide and oil carrier quotation.

VIKING

Landboumiddels - Diensverskaffers aan Eindgebruikers | Lid van / Member of CropLife SA | Agricultural Remedies - Service Provider to End Users

Viking Bemarking (Edms) Bpk | Viking Marketing (Pty) Ltd

Reg.Nr.1996/012179/07 | Reg.No.1996/012179/07

Posbus / P.O. Box 51 h/v Riesling en Shiraz Straat / Road Saxenburg Park 1 Blackheath 7581 Tel (021) 907-3000 Faks / Fax (021) 905-7113 Web www.viking.co.za

Attention: Kyle

9 October 2020

Dear Kyle

Herewith we are pleased to submit our prices as per your request. Prices do not include VAT and are nett for payment within 30 days after our original statement. Should you not have a direct account with Viking Marketing please note that product will be released once payment has been cleared.

We shall try to hold the quoted prices for as long as possible; however, due to the fact that suppliers change their prices to us without notice, the quoted prices can only be held firm for as long as our current stocks last, and our supplier prices remain the same. Kindly check with myself or with our Saxenburg office when ordering.

Product	Pack Size	Price per litre (VAT excluded)
Citrole	20 lt	R33.44
Garlon	1 lt	R233.78

Please note that the quoted price is for collection at our warehouse in Blackheath.

Thank you for the opportunity to quote.

Kind regards

Janet